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THE RELATIONSHIP OF EEG TO READING DIFFICULTY: A NEUROPHYSIOLOGICAL ASSESSMENT

by

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A THESIS

Submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Education.

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled The Relationship of EEG to Reading Difficulty: A Neurophysiological Assessment submitted by David L. Mensink in partial fulfilment of the requirements for the degree of Master of Education.

ABSTRACT

The present research study was conducted to compare electrophysiological recordings of the left and right cerebral hemispheres of elementary school children who received lower scores on a reading achievement test with those who received higher scores on the same test. The purpose was to see if a relationship exists between electrophysiological recordings of the human cerebral cortex and proficiency in reading for children aged 9 and 12 years old. The major focus of the study was on assessment and not on either etiology or remediation. Accordingly, the EEG technique was used to determine if children having difficulty in learning to read would display a different pattern of electrophysiological activity during cognitive tasks as compared to normal readers.

The final sample was composed of 14 Grade 3 and 14 Grade 6 students from two Edmonton Public schools. In order to include some students who had reading problems, only classes which provided remedial reading for a portion of the students (resource room program) were considered. The sample included 9 males and 5 females in Grade 3 (average age of 9.1 years old) and 11 males and 3 females in Grade 6 (average age of 12.0 years old). For each grade level, the sample was divided into two equal groups on the basis of Edmonton Public School District Reading Achievement Test scores. Students who received a score below the median score on the reading test were defined as "low readers" and students who received a reading test score above the median score were defined as high readers. Thus, there were 7 low and 7 high readers for each grade level. In addition, the Slosson Intelligence Test was administered to the 28 subjects to determine the ability level of each group.

The experimental apparatus was an EEG measuring device connected to an Apple II microcomputer (Biocomp 2001). Electrodes filled with conductive paste were placed over the left and right cerebral hemispheres on the skull of each subject. Subjects were then asked to orally read a passage, copy nonmeaningful designs, and rest during which time their EEGs were recorded and stored by the computer. EEG epochs lasting 90

seconds each were recorded twice for each task over each cerebral hemisphere. Hence, four recordings were collected for each task -- two over each hemisphere. The experimental procedures for each subject lasted about 60 minutes.

The statistical ANOVA technique was used to analyze the data. Accordingly, group (low and high readers) by hemisphere (left and right) by task (reading, drawing, resting) ANOVA's with repeated measures on hemispheres and tasks were calculated for the study. In addition, the Scheffe' multiple comparison technique was used for making a posteriori tests on the individual means.

Results were discussed in terms of the cerebral asymmetry displayed by each reading group at each grade level. In general, it was found that there was no difference between the low and high reading groups with respect to cerebral asymmetry. This was found at both grade levels. Therefore, results from the study do not support the notion that poor readers suffer from a lack of hemispheric specialization. However, it was found that Grade 3 children engaged or activated their left hemispheres more than their right hemispheres. This finding was attributed to the over-emphasis on analytic-sequential tasks in the elementary school setting. Also, it was found that poor readers at the Grade 6 level activated their cerebral hemispheres more than good readers in Grade 6. It was suggested that this latter finding was a result of the greater difficulty poor readers may have had in completing the cognitive tasks.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF CHARTS

CHAPTER I

INTRODUCTION

INTRODUCTION

An eminent topic in the research literature on reading problems is that of cerebral function and dysfunction. To wit, a number of recent publications specifically examine the relationship between neuropsychology and learning or reading disorders (Benton and Pearl, 1978; Gaddes, 1980; Knights and Bakker, 1976; Pirozzolo, 1979; Tarnopol and Tarnopol, 1977). A motivating force behind investigations on the neuropsychology of learning/reading disorders is the hope that a clear understanding of cerebral function/dysfunction will lead to useful remedial methods. Although such an undertaking has begun, it is still in its infancy. Spreen (1976) states the following on this matter:

> I think we should be modest in our attempt at building a neuropsychology of learning disorders. We are building a theoretical model of brain functioning that tries to encompass the normal and the abnormal learner. The model should contribute to our understanding of the normal learning process and it should have pragmatic value, eventually resulting in proven remedies based on that theory (p. 447).

A very strong contention proposed here is simple but appropriate -- a <u>clear</u> understanding of brain structure and function is a necessary prerequisite to and corequisite of remedial strategies based on psychophysiological/neuropsychological properties. The modest proposal suggested here is that a clear understanding of brain structure and function has not yet been achieved and, therefore, physiologically based remedial strategies for reading problems are more appropriately situated in the research laboratory than in the reading clinic. Justification for the above statement will become obvious throughout the present study.

The purpose of the present study is to compare the cerebral organization of younger and older children at two levels of reading achievement during cognitive challenges. A number of terms used in the above statement of purpose need to be operationally defined. Cerebral organization is defined as differential involvement of the two cerebral hemispheres during higher mentation. For the purpose of the present study, cerebral

organization is ascertained by electrophysiological recordings (EEG) measured in amplitude from the posterior regions of each cerebral hemisphere. Younger children are aged 8 to 10 years old and older children are 11 to 13 years old. The two levels of reading achievement (low and high) are determined on the basis of a group reading achievement test (decoding and comprehension). Low readers are those achieving below the median on such a test and high readers are those achieving above the median;relative to children of the same age. Finally, cognitive challenges are reading orally and drawing nonmeaningful designs. In short, the major purpose here is to determine if the differential pattern of EEG amplitude for low readers differs from that of high readers during reading and drawing tasks. The differential pattern of EEG amplitude is an operational method of determining hemispheric specialization of cerebral asymmetry of function (i.e. greater activation during one task than another on the same hemisphere). Hemispheric specialization will be explained later.

Prior to presenting a rationale for the study, it is important to note what is not being proposed. The purpose of the forthcoming research study is <u>not</u> to:

1. define reading disability,
2. propose an etiology of reading disability,
3. suggest a unitary remedy for reading disability on the basis of known psychophysiological properties, and
4. generalize findings to populations of good and poor readers.

Clearly, the above proposals are beyond the scope of the present purpose. A single definition, etiology, and remedy are probably inappropriate regardless of the study.

The rationale for the study lies in the area of assessment. One contribution of medical and computer sciences to the field of education is a new technology for assessing children with reading problems. As will be discussed in Chapter II (review of literature and research), a number of

medical researchers are combining their knowledge of brain structure/ function with computer technologists and using computerized EEG devices to assess the cerebral organization of children with reading problems. The reason for conducting the present study then rests on the belief that such contributions are valuable for the field of education, that existing research on brain-behavior relationships of poor readers rests on empirical knowledge about human neuropsychology, and that more research is required in this field. At bottom, education and, in particular, special education can be greatly enhanced by seriously considering research in the fields of neuroanatomy, neuropsychology, neurophysiology, psychophysiology, and electrophysiology. Suffice it to say that the present study is an attempt to learn from some of the disciplines mentioned above. Herein lies its rationale.

OVERVIEW

The general problem of interest here is that there are children who despite normal ability, adequate instruction, intact senses, and neurological integrity have difficulty in learning to read. In addition, new approaches to assessment seem to be warranted (see Coles, 1978). The present study will attempt to address these problems by considering an area which may be thought of as the intersection between the research areas of special education, neuropsychology and reading. In so doing, it is necessary to briefly summarize some information in the fields of neuropsychology and reading.

Neuropsychology and the Processing of Language

The following publications provide the "novice" with excellent introductions to brain structure and function: Dimond, 1972; Gaddes, 1980; Hecaen and Albert, 1978; Luria, 1973; Scientific American, 1979; Tarnopol and Tarnopol, 1977 (Chapter 1); Walsh, 1978; Whitaker, 1971; and Wittrock, 1977. The intention here is not to summarize the information presented in the above publications but rather to highlight just a few areas which pertain to the forthcoming study. First a number of terms will be defined and then some comments on the structure and function of the human brain will follow. Finally, three conclusions about the "double brain" made by Dimond (1972) will conclude this section of the introduction.

Talbot (1977) compiled a glossary of terms which appear at the end of Wittrock's book, The Human Brain (pp. 185 - 207). Pertinent definitions are as follows:

> Broca's area. An area in the human frontal cortex of the left hemisphere that has been closely related to both syntactic and phonemic aspects of language function.
>
> Corpus Callosum. A massive compact bundle of axons connecting the right and left cerebral cortices. ... The corpus callosum thus allows the two halves of the cerebral cortex to communicate directly with one another.

Frontal lobe. The most anterior lobe of the cerebral cortex encased in large part by the forehead and temples. This region contains the motor area of the cerebral cortex.

Neuron. The nerve cell; the basic functional unit of the nervous system.

Occipital lobe. The lobe of the cerebral cortex directly behind the parietal and temporal lobes and adjacent to the skull along the lower, back position of the head. This region consists largely of the area of the cerebral cortex most directly in receipt of visual (light) information.

Parietal lobe. The cerebral cortical lobe directly behind the frontal lobe and immediately above the posterior end of the temporal lobe. This region contains the area of the cerebral cortex most directly in receipt of sensory information from the skin and muscles: touch, pressure, position sense, etc.

Splenium. The large posterior expansion of the corpus callosum through which the visual and auditory areas in one-half of the cerebral cortex communicate directly with the visual and auditory areas in the other half of the cerebral cortex, respectively.

Temporal lobe. The lowest lying lobe of the cerebral cortex, located below the frontal and parietal lobes and adjacent to that portion of the skull just above the ears. This region contains the area of the cerebral cortex that receives auditory information most directly.

Wernicke's area. An area in the left cerebral hemisphere near the border between the temporal and parietal lobes, critical to language comprehension.

The diagrams by Whitaker (Figure 1 and 2) display some of the areas defined above.

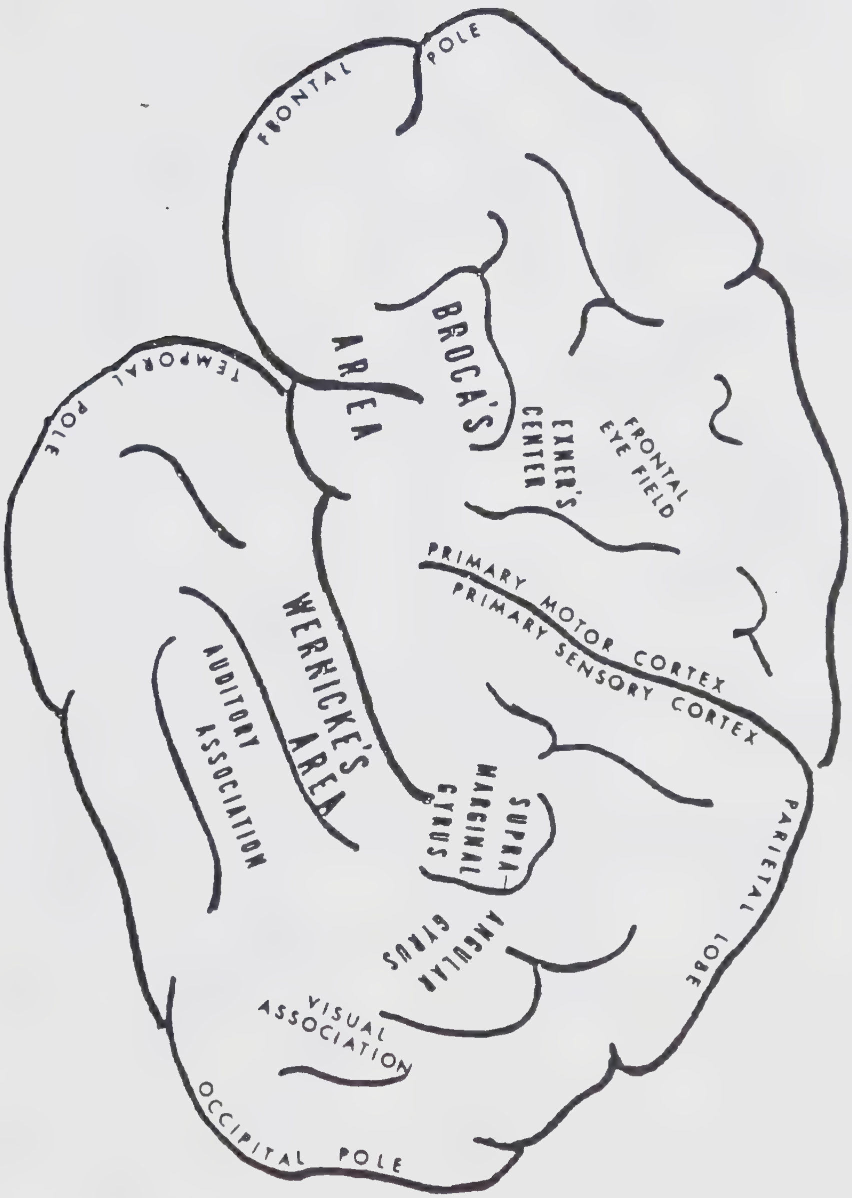

Figure 1 Left Hemisphere Language Areas
(From Whitaker, 1971)

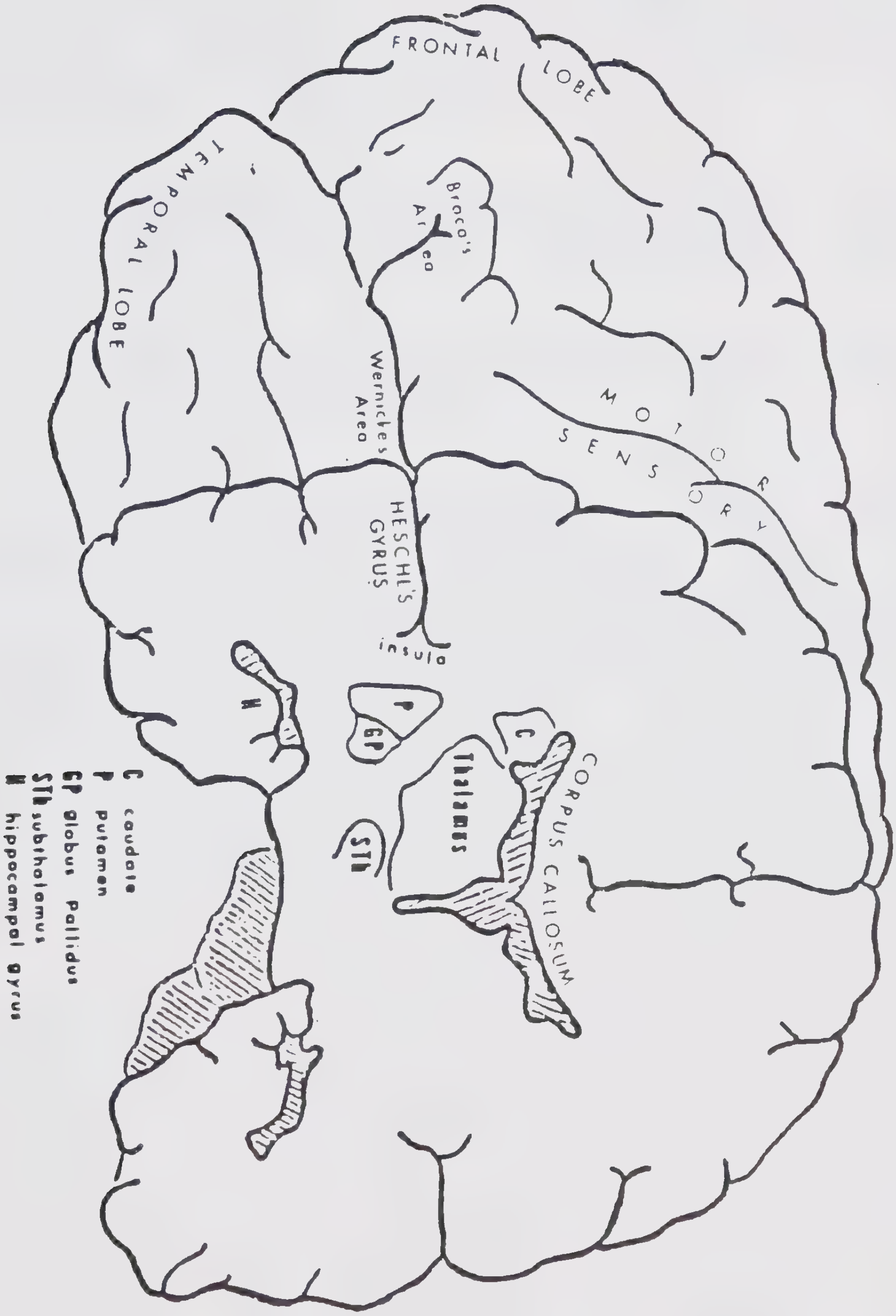

Figure 2 Coronal Section Through Heschl's Gyrus

(From Whitaker, 1971)

The relationship between cerebral structure (neuroanatomy) and function (neurophysiology) has been a controversial issue throughout the history of neuropsychology. Historically, two extreme positions have been proposed (Hecaen and Albert, 1978):

1. Localization: there exists an isomorphic relationship between a particular cerebral structural area and a particular mental activity.

2. Wholistic: there is no specific structure which can account for a particular mental function; rather, various cerebral areas work together.

A.R. Luria, a Russian neuropsychologist, offers one solution to this controversy on the basis of his work with brain-injured patients. Luria (1973) conceptualizes brain function as "... organized in systems of concertedly working zones, each of which performs its role in a complex functional system....(p. 31). He does suggest that the brain functions according to the law of diminished specificity. To explain, according to Luria there are three functional units of the brain: 1) the unit for regulating tone or arousal (subcortex and brain stem); 2) the unit for receiving, analyzing, and storing information (occipital, temporal, and parietal lobes); and 3) the unit for programming, regulating, and verifying mental activity (frontal and pre-frontal lobes). Moreover, as conceptualized by Luria, each unit is organized or arranged in a hierarchical structure, depending on the engaged cognitive activity, from primary (information reception) to secondary (information processing and retrieval) to tertiary or overlapping zones (information association and integration). The law of diminished specificity posits that the greatest structural specificity is present for primary zones and the least specificity is present for the tertiary zones. Therefore, both of the two extreme positions may be correct depending on the zone and/or level of cognitive activity. On this matter, Hecaen and Albert (1978) would add that the "... complex interrelations among cortical neurons do not negate the concept of functional localization. ... Each cerebral zone may contain diverse functional potentialities while remaining primarily responsible for certain specific

behavioral skills (p. 404)." This short discussion of a very complicated issue does not solve the problem but, hopefully, will permit one to consider cerebral correlates of linguistic activity which is the next topic for discussion.

In discussing the processing of linguistic stimuli, cerebral structure and function come together. Geschwind (1979) clearly explains this process:

> Linguistic competence requires the cooperation of several areas of the cortex. When a word is heard, the sensation from the ears is received by the primary auditory cortex, but the word cannot be understood until the signal has been processed in Wernicke's area nearby. If the word is to be spoken, some representation of it is thought to be transmitted from Wernicke's area to Broca's area, through a bundle of nerve fibers called the arcuate fasciculus. In Broca's area the word evokes a detailed program for articulation, which is supplied to the face area of the motor cortex. The motor cortex in turn drives the muscles of the lips, the tongue, the larynx and so on. When a written word is read, the sensation is first registered by the primary visual cortex. It is then thought to be relayed to the angular gyrus, which associates the visual form of the word with the corresponding auditory pattern in Wernicke's area. Speaking the word then draws on the same systems of neurons as before (p. 190).

See figures 3 and 4 for Geschwind's diagrams of the neural structures involved in processing language. Of course, the entire process is far more complicated than that presented here since subcortical areas (e.g. thalamus) are also involved.

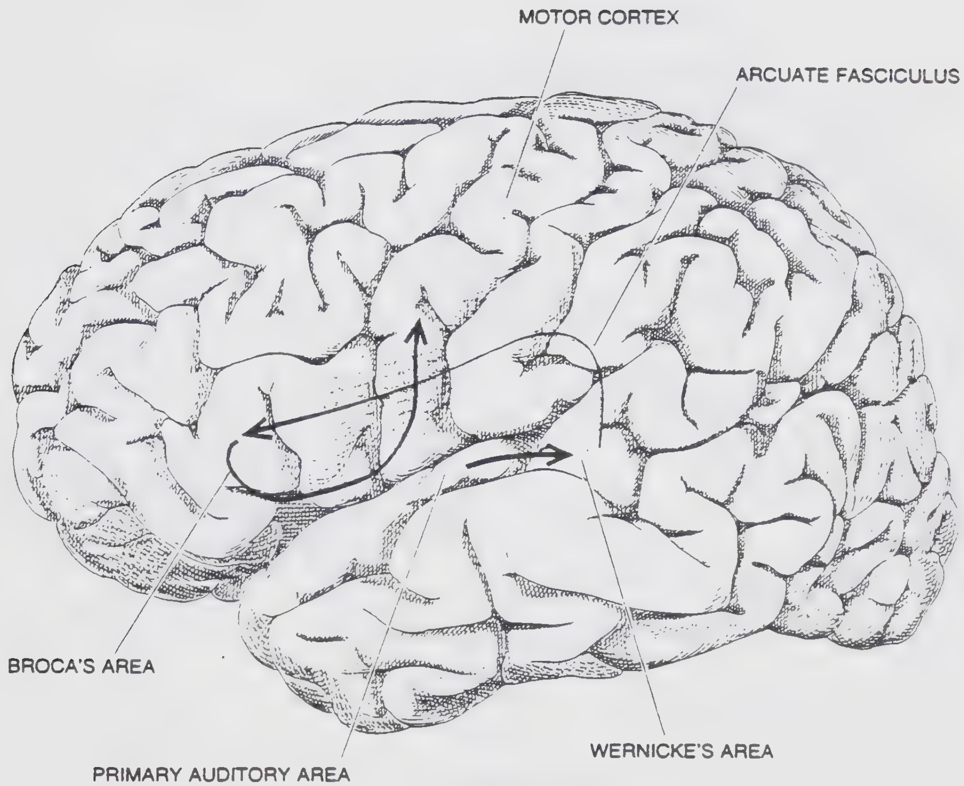

Figure 3 Neural Structures Involved in Speaking a Heard Word (From Geschwind, 1979)

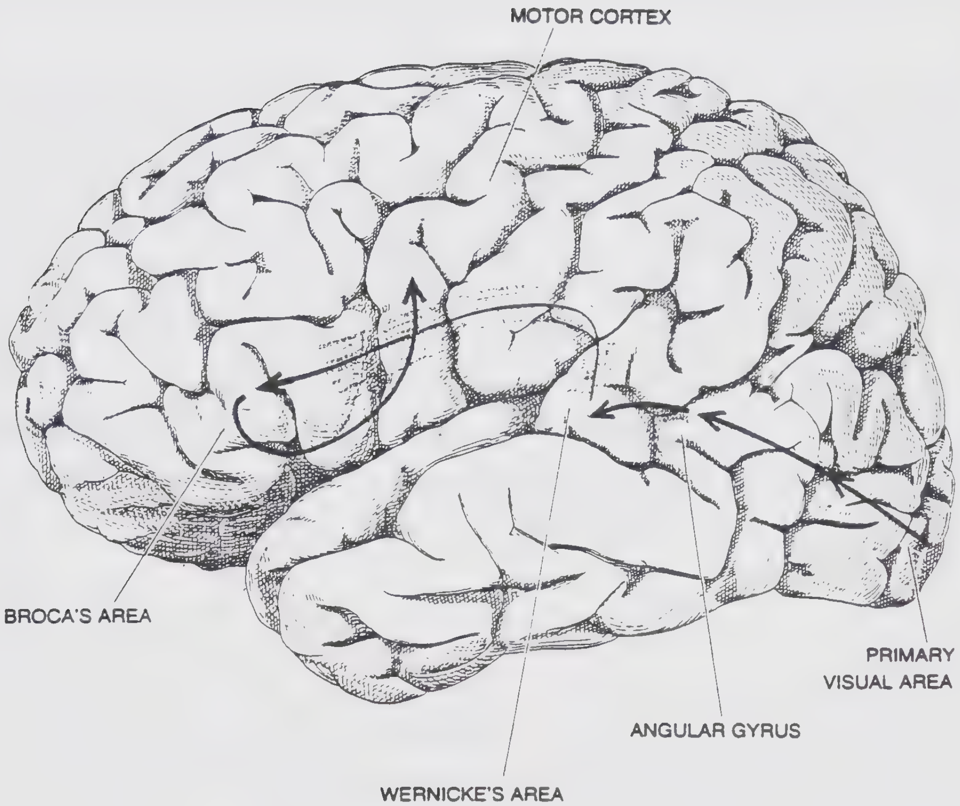

Figure 4 Neural Structures Involved in Speaking a Written Word (From Geschwind, 1979)

Finally, three conclusions by Dimond (1972) about the "double brain" will serve as an introduction to the topic of hemispheric specialization or cerebral asymmetry which is a major topic of the present study. In his book, The Double Brain, Dimond reviews and discusses studies of brain lesions in humans and animals, studies of hemispherectomies and sections of the corpus callosum, and studies of normal human behavior. On the basis of this evidence, Dimond suggests the following:

> From these sources it is possible to draw three overall conclusions. The first is that the two-brain interpretation is valid both for the nervous system of man and for that of lower animals. Secondly, that the bilateral arrangement allows the total productive capacity of the brain to be increased. Thirdly, that the hemispheres do not work in an all or none fashion, but take part in a highly integrated fusion of functions which is mediated largely by the transporting action of the corpus callosum (p. 193).

These conclusions are crucial to the forthcoming study. The final section of the introductory chapter will overview some preliminary information on reading.

The Reading Process

The purpose here is not to propose a precise model for the acquisition of reading but rather to suggest a possible perspective on the learning to read process. The perspective suggested here is developmental -- reading is a process. According to Smith (1978), "reading is less a matter of extracting sound from print than of bringing meaning to print (p. 2)". The view taken here is that bringing meaning to print is a goal or aim of reading which is more pronounced in later reading stages than in early stages of reading. That is, the task of comprehending written script is certainly germane to the entire learning to read process but it is more active during the "fluent" reading stage. Reading then is conceptualized as being an aspect of cognitive growth which parallels, and may contribute to, cognitive development. Such ideas are generated by Paul Satz's theory on developmental dyslexia (discussed in Chapter II).

In learning to read then,various skills and cognitive processes are required. Calfee (1977) suggests that the range of skills directly related to the acquisition of reading are (pp. 295 - 296):

1. visual perception of letter strings,
2. auditory-phonetic analysis of spoken words,
3. letter-sound correspondences,
4. association of a letter string with a lexical mode in memory, and
5. a variety of comprehension skills.

Perhaps these subskills follow a developmental sequence as reading is acquired. According to Gibson (1970):

> Once a child begins his progression from spoken language to written language, there are, I think, three phases of learning to be considered. They present three different kinds of learning tasks, and they are roughly sequential, though there must be considerable overlapping. These three phases are: learning to differentiate graphic symbols; learning to decode letters to sounds ("map" the letter into sounds); and using progressively high-order units of structure (p. 317).

The sequence in learning to read may follow the sequence in language acquisition -- phonology, morphology, syntax (see McLean and Snyder-McLean, 1978). Or it may parallel overall cognitive development -- enactive, iconic, and symbolic representation (see Bruner, 1968). If stage theories of cognitive development (Piaget, Bruner) are accepted then it may make sense to consider learning to read as a development process. This is the perspective proposed here.

CHAPTER II

REVIEW OF THE LITERATURE AND RESEARCH

HEMISPHERIC SPECIALIZATION OF THE HUMAN CEREBRAL CORTEX

The first section of the present review is largely devoted to empirical studies of normal human subjects. First, morphological or structural properties of the cerebral cortex will be reviewed. Next, functional properties on information processing of the brain will be discussed. Accordingly, a model of hemispheric specialization will be presented. Finally, various theories regarding the age of onset of hemispheric specialization will be presented. The purpose of this section of the review will be to examine hemispheric specialization of normal subjects in order to set the groundwork or background for information pertaining to subjects having difficulty in learning to read.

The next section will be largely devoted to describing deficits associated with reading difficulty. And the final section of the review will deal with the relationship between reading difficulty and hemispheric specialization. The review is to provide a rationale for conducting neurophysiological research on children who have difficulty in learning to read. A presentation of hypotheses which are to be empirically tested for the present study will conclude the review of literature and research.

Structural Asymmetry of the Human Brain

Two questions regarding structural asymmetry of the human brain are:

1. Is the left hemisphere morphologically different from the right? and,

2. How should this possible structural difference be interpreted or understood?

The major reason for investigating structural cerebral asymmetry is to propose a basis for differentiation. That is, if the two hemispheres are shown to be structurally different then one might infer that they function differently, as well.

Several researchers have concluded on the basis of their studies that the two cerebral hemispheres are structurally different. Geschwind and Levitsky (1968) performed postmortem examinations on 100 adult human brains which were free of significant pathology. They found that the planum temporale (the area behind Heschl's gyrus in the temporal lobe) was larger on the left hemisphere in 65% of the brains and it was larger on the right hemisphere in only 11%. Further, the left planum was, on the average, one-third longer than the right planum. Geschwind and Levitsky (1973) state that "... the planum temporale contains auditory association cortex which extends on to the lateral surface of the posterior portion of the first temporal gyrus. These regions of auditory association cortex on the left constitute the classical Wernicke's area, a region known from anatomical findings in aphasiac patients and from stimulation studies during neurosurgical procedures to be of major importance in language functions (p. 187)."

Postmortem examinations of 16 adult and 14 infant brains were conducted by Witelsen and Pallie (1973). The left planum temporale was found to be larger in both neonate and adult brains. They conclude that "... since the asymmetry occurs in an area of relevance to language

function and in the direction compatible with known functional asymmetry for language, the anatomical data have considerable behavioral implications (p. 644)." Regarding planum asymmetry, similar results were obtained by Wada, Clarke, and Hamm (1975) who examined the brains of 100 adults and 100 infants. Galaburda et al. (1978) report about a study that found the volume of the left temporoparietal cortex to be seven times larger than the right. They also report on studies which found the following morphological asymmetries:

1. the left occipital lobe is wider than the right,

2. the left Sylvian fissure is longer than the right, and

3. the right frontal lobe is wider than the left.

Moreover, these findings were more striking for right-handed subjects.

Ratcliff et al. (1980) conducted an experiment in which they selected files of patients "... who had had bilateral angiograms and whose speech representation had been clearly established as left, right, or bilateral on the basis of sodium amytal tests ... (p. 90)." In total, their sample consisted of 59 patients (39 with left-hemisphere speech, 11 with bilateral speech, and 9 with right-hemisphere speech). Ratcliff and his colleagues found greater asymmetry in the posterior sylvian region of patients with left-hemispheric speech representation than in patients with atypical cerebral dominance for speech. However, they suggest that there are three problems with equating morphological asymmetry with functional asymmetry:

1. structural asymmetry has been found in areas outside the posterior Sylvian region where functional significance of the asymmetry is less clear.

2. the percentage of brains showing typical posterior Sylvian asymmetry, averaged across studies, is about 73% which is lower than one would expect for left-hemisphere dominance for speech, and

3. only 30% of left-handed subjects show typical asymmetry (i.e. similar to right-handed subjects with left-hemispheric speech representation) and this figure should be closer to 60% (p. 89).

Evidence contrary to the above findings exists in research literature. Rubens (1977) reports on a study conducted by himself and others which found that the retrosylvian parietal region including the angular gyrus is smaller on the left side. He states:

> ... the smaller left angular gyrus goes against the theory that language dominance of the left hemisphere is based on its superiority to make cross-modal associations and that this superiority occurs by virtue of the greater development of the left angular gyrus (p. 513).

According to Rubens, more definitive cytoarchitectural and gross morphological studies which correlate with functional studies are necessary. Whitaker and Ojemann (1977) highlight studies which found that Heschel's gyrus, Broca's area, and the superior temporal gyrus are longer in the right hemisphere than in the left. These areas are also involved in the processing of linguistic information. In addition, the right hemisphere has been found to be heavier than the left. Concerning findings on the morphological asymmetry of the planum temporale, Whitaker and Ojemann state that "it seems unwise to associate language per se with consistent left-greater-than-right differences of only one portion of the cortical language areas (p. 460)."

The first of the two questions stated at the beginning of this section (Are there morphological differences between the two hemispheres?) has been answered in the affirmative. The problem relates to the question on interpretation. How should these differences be interpreted? First, structure and function are not necessarily isomorphic. Moreover, since various areas involved in language have been found to be both larger and smaller in the left hemisphere as compared to the right, morphological differences need to be interpreted with a great deal of caution. Finally, functional asymmetry can be assessed by using other methods of investigation.

Rather than inferring functional asymmetry from morphological studies or using these studies as "proof" for functional asymmetry, it is perhaps more meaningful to consider how well findings from structural studies correlate with findings from functional studies.

Functional Asymmetry of the Human Brain

A number of methods have been used to determine if the left and right cerebral hemispheres function differently. Among these methods are dichotic listening, tachistoscopic presentation, electroencephalography, evoked potential, and regional cerebral blood flow. Findings from each of these methods will be reviewed.

Prior to discussing experimental findings, the concept of hemispheric specialization will be explained. Dimond and Beaumont (1974) propose the following model of the association of different functions with hemispheric locus (p. 83):

Left Hemisphere Channel	Both Hemispheres	Right Hemisphere Channel
Speech and language	Simple motor responses	Spatial Integration
Complex motor function	Incidental learning	Calculation
Vigilance	Fatigue processes	Creative - Associative Thinking
Paired - Associate Learning		

Dimond and Beaumont posit that the hemispheres work together and that each hemisphere has a capacity to perform similar tasks but that one hemisphere exceeds the other in proficiency with respect to its specialized task. This model portrays the meaning of the term "hemispheric specialization" as it will be used here.

Dichotic Listening Studies

The dichotic listening technique has been used to study cerebral dominance. In 1961, Kimura discovered that when verbal stimuli were simultaneously presented to the two ears, the stimuli presented to the right ear were more accurately reported than those presented to the left ear (Krashen, 1976, p. 158 - 159). This right-ear advantage (REA) has been interpreted as evidence for the proposition that the left hemisphere of right-handers is specialized to process verbal information. Krashen (1976) describes mechanisms involved in producing the REA:

> Under normal conditions, auditory stimuli arriving at the ears travel along contralateral (crossed) and ipsilateral (uncrossed) pathways to bilaterally situated primary auditory receiving areas (Heschl's gyri) in each temporal lobe. The primary auditory receiving areas in each cortex receive input from both ears; for example, the contralateral pathway from the right ear and the ipsilateral pathway from the left ear both input the left primary auditory receiving area. The primary auditory receiving areas 'hear' sounds but intelligent recognition is the function of higher cortical areas.
>
> In the case of language, higher analysis is performed by several areas in the left hemisphere. The left primary auditory receiving area has a more direct pathway to the language areas than the right primary auditory receiving area. Stimuli arriving at the right receiving area must cross from the right to the left hemisphere before they can be processed by the language areas.
>
> There is convincing evidence that under dichotic listening conditions the ipsilateral pathways are suppressed or inhibited. This evidence comes from several dichotic listening experiments using split-brain and hemispherictomized subjects (p. 159).

In short, stimuli presented simultaneously to both ears are more effectively processed and analyzed by the contralateral hemisphere since contralateral pathways are presumably predominent over ipsilateral pathways. If this information is verbal, then a right-ear advantage will be expected since the theory postulates that the left-hemisphere is specialized to process linguistic information. Thus, a right-ear advantage for speech stimuli implies a left-hemisphere dominance, and a left-ear

advantage for nonspeech sounds implies right-hemisphere dominance. An important point to remember is that dichotic listening experiments investigate verbal production (expression) and not just verbal reception. Findings from some dichotic listening studies using normal subjects will now be discussed.

Using the dichotic listening procedure in combination with the non-nutritive High Amplitude Sucking (HAS) paradigm, Entus (1977) found that infants (age 22 to 140 days) displayed a right-ear advantage to speech sounds (consonant - vowel syllables) and a left-ear advantage to music stimuli ("A" note on the bassoon, cello, piano, and viola). Upon presentation of speech stimuli, 71% of the infants showed a right-ear superiority and upon presentation of music stimuli, 79% showed a left-ear superiority. Entus concludes that her findings "... agree with the available neuroanatomical and physiological evidence in suggesting that hemispheric asymmetry is part of man's biological endowment and that it is functional by 3 weeks of age (p. 72)."

The age of onset of hemispheric specialization (inferred from dichotic listening experiments) is a controversial issue in the research literature. The following results were found from an experiment conducted by Satz et al. (1975):

1. significant ear asymmetry was not found in children younger than nine years of age;

2. the magnitude of the difference between ears, while not significant until age nine, continued to increase with age until eleven at which time the slope functions for each plateaued;

3. ear asymmetry was independent of sex (abstract, p. 171).

Dutch-spoken digit-pairs were presented to approximately 20 boys and 20 girls at each of five ages (5, 6, 7, 9, 11). Satz et al. state: "...one might conclude, on the basis of the present results, that the ear asymmetry,

regardless of its age of onset, does undergo major changes after five years of age (p. 184)." Moreover, they suggest that an increase in the magnitude of the ear asymmetry is compatible with the process of speech-brain laterlaization.

Similarly, Davidoff, Cone, and Scully (1978) conducted a study in which 120 children at age 6, 8, and 10 listened to a dichotic stop consonant tape (e.g. pa, ga). They found that the 6-year-old group showed less right-ear advantage but the lower S.E.S. 6-year-olds were mainly responsible for this effect. After age 6, it was found that the right-ear advantage increased with age. Davidoff et al. conclude that "... there is an effect of learning to read that is associated with an increasing left-hemisphere advantage for linguistic tasks (p. 226)."

The characteristic right-ear advantage for linguistic information has been found in a number of experiments (Krashen, 1976, pp. 162 - 167). The intriguing question regarding the onset of cerebral specialization and its meaning will be addressed throughout the present review. It is important to note here that certain problems are associated with dichotic listening studies. First, as pointed out by Springer (1977), "intensity, spectral composition, and temporal variables each markedly affect the ear asymmetry (p. 333)." Secondly, dichotic listening techniques may not yield a "pure" measure of hemispheric asymmetry. Springer (1977) states:

> With the dichotic procedure, two inputs are presented simultaneously to a subject, one to each ear. Although each ear sends projections both contralaterally and ipsilaterally from the superior olivary complex upward, simultaneous presentation seems to be effective in suppressing the ipsilateral inputs. Split-brain subjects are able to report some left-ear material presented dichotically, however, suggesting that suppression is not complete and hence that the dichotic paradigm may in some instances not satisfy the initial requirement of lateralized input (p. 332).

Finally, Satz (1977) cautions against inferring hemispheric asymmetry on the basis of findings from dichotic listening experiments. He states that "the problem ... concerns the assumption that because a relationship exists between two variables (e.g. ear asymmetry and speech-brain lateralization)

then inductive inferences can then be made on individual Ss to classify them into respective hemispheric dominant groups (p. 208)." Using a Baysean analysis, Satz shows that this assumption may be unwarranted.

Tachistoscopic Studies

Tachistoscopic studies have also been used to answer questions on hemispheric specialization. The procedure usually involves flashing linguistic and non-linguistic information to the left and/or right visual fields for a short period of time (less than 200 milliseconds). The subject is then asked to recall or recognize the information presented. A left visual field advantage is obtained if the subject recalls or recognizes more information presented to the left visual field than the right visual field and a right visual field advantage is obtained if the subject recalls or recognizes more information presented to the right visual field. Information presented to each field (left or right) is primarily processed by the contralateral hemisphere (Beatty 1975). Mechanisms underlying visual information processing are highlighted by Whitaker (1971):

> The principal optic characteristics are well known: the right half of the visual field is focused on the left half of each retina, and vice versa. Each optic nerve carries a right and a left half-field (divided vertically) to the optic chiasma where the pathways carrying left visual field information (from the right retinas) converge in the optic tract of the right hemisphere; right visual field information proceeds in the optic tract of the left hemisphere (p. 68).

In short, the left hemiretina of each eye receives information from the right visual field and this information is then sent to the left cerebral hemisphere; likewise, the right hemiretina of each eye receive information from the left visual field and this information is sent to the right cerebral hemisphere. Therefore, if the left hemisphere surpasses the right in processing verbal information then one could expect to find a right visual field advantage upon tachistoscopic presentation of verbal information. And if the right hemisphere surpasses the left in processing nonverbal information then one would expect a left visual field advantage when nonverbal stimuli are presented. Some experimental findings on tachistoscopic

presentation of verbal and nonverbal information to normal subjects will be reviewed.

Mckeever and Huling (1971a) conducted an experiment in which 20 normal right-handed adult subjects performed a monocular tachistoscopic word recognition task. Ten of these subjects constituted the left-eye viewing group and the remaining 10 subjects were the right-eye viewing group. Four letter nouns were flashed two at a time (one word to the left and one to the right of fixation) for a period of 20 milliseconds. Right visual field superiority (left-hemisphere) was significant across all subjects and for both left and right eye viewing groups. On the basis of this study, McKeever and Huling proposed the right visual field superiority is a result of a shorter neural pathway between the right visual field and the left hemisphere language centers as compared to the neural pathway between the left visual field and the left hemispheric language center. However, this proposal was not confirmed by another experimental procedure (McKeever and Huling, 1971b). The method used was to "lead" or "lag" one or the other visual half-field word presentations. The experimenters found that "... allowing earlier left-field word presentation failed to increase left-field recognitions and the typical right-field recognition superiority obtained in all conditions (abstract, 1971b)." Observed right field superiority for verbal stimuli appears to be a result of factors other than those related to transmission time between the left cerebral language centers and the left and right visual fields.

Other studies confirm that right visual field superiority is obtained when linguistic information is presented with a tachistoscope. Rosen et al. (1975) flashed four letters in each field (100 milliseconds) to 20 right-handed adults. They conclude that the right field superiority is a result of left cerebral dominance for language. Mackavey, Curcio, and Rosen (1975) found right visual field superiority using bilateral presentation of word pairs in four tachistoscopic experiments. For these four experiments, MacKavey et al. varied the exposure time (20 milliseconds, 70 milliseconds, or 100 milliseconds) and the placement of words (vertical or horizontal). Also, in two of the experiments they asked the

subjects to fixate on a digit prior to presenting each word pair. Mackavey et al. (1975) conclude that "...the right visual field superiority for bilaterally presented word pairs is extremely robust (p. 31)." Vertical presentation of words was used to minimize (left and right) directional scanning. Hines (1975) presented the following pairs (one in the left and one in the right visual field) with a tachistoscopic to a total of 63 adult subjects: words with words, words with shapes, words with faces, shapes with shapes, and faces with faces. Hines found a large right field superiority for words, a small but significant right field superiority for shapes (inkblots), and no visual field superiority for faces (photographs). Hines suggests that "... the large right visual half field superiority with bilateral presentation reflects the superior verbal recognition ability of the left hemisphere (pp. 140 - 141)." Similarly, Leehy and Cahn (1979) found a right visual field superiority for word recognition and a left visual field superiority for recognition of both familiar and unfamiliar faces. They presented the stimuli bilaterally with various exposure durations to right-handed adults. Words were exposed for a duration of 80, 100, or 120 milliseconds, familiar faces for 60 milliseconds and unfamiliar faces for 120 milliseconds. On the evidence from the above experiments one can conclude that tachistoscopic presentation of verbal information results in a right visual field superiority, at least; for normal right-handed adults. By inference, many of the experimenters propose right field superiority is a result of the specialized capacity the left hemisphere has in processing verbal information.

One further study on tachistoscopic presentation of information to normal subjects addresses the issue of development and hemispheric specialization. This study was conducted by Carmon, Nachshow, and Starinsky (1976). Four groups, each composed of 48 Hebrew speaking children were selected to participate -- 24 boys and 24 girls aged 6, 8, 10, and 12 years old. The stimuli presented were single Hebrew letters, two-letter and four-letter Hebrew words, and two-digit and four-digit numbers. Note that the Hebrew letters and words are read from right to left and the numbers are read from left to right. This is a strength of the

experiment since it controls for the plausible confound of directional reading habits (usually left to right in English speaking subjects) which could bias the results in favor of the right visual field. Carmon et al. tachistoscopically presented the stimuli for exposure durations of 12.5 to 100 milliseconds, both unilaterally (one stimulus at a time in either the left or right visual field) and bilaterally (stimuli pairs -- one in each visual field). Carmon et al. (1976) state:

> The present study demonstrated that acquisition of directional reading habits does not influence visual hemifield asymmetries in perception of verbal material. Both Hebrew words and Arabic numbers, though scanned in opposite direction, were perceived generally better in the right hemifield. This finding suggests that hemispheric specialization in verbal perception is the underlying source of laterality differences (p. 467).

In addition, they found that although the right visual field superiority did not interact significantly with age, a trend of developmental strengthening in the perceptual asymmetry was noted (p. 467). This latter finding would tend to concur with that found by Satz et al. (1975) and Davidoff et al. (1978) who used the dichotic listening technique.

Various problems involved with the use of a tachistoscope as a measure of hemispheric specialization have been suggested. The short exposure time (usually less than 200 milliseconds) limits the complexity of the stimuli (Springer 1977). According to White (1972), tachistoscopic experiments typically require subjects to report either verbal or give written responses but such a procedure does not investigate verbal encoding or analysis. He states that "... because the left hemisphere is usually prepotent for language and speech processes and initiation of vocal motor responses, it does not necessarily follow the same hemisphere as prepotent or 'dominant' for stimulus analysis (p. 504)". Finally, White (1973) suggests a number of task-specific factors which might affect the degree or direction of lateralization: number of letters, spacing of letters, retinal locus, exposure duration, report instructions, and directional stimulus characteristics.

Electroencephalographic (EEG) Studies

The electroencephalogram is a record of electrical activity in the brain. According to Marshall (1967), "electroencephalography, by definition, is the recording and evaluation of the electrical potentials generated by the brain and sampled at the scalp surface (p. 221)." Basically, the EEG consists of two measures of spontaneous electrical rhythms recorded from the surface of the scalp: 1) frequency (measured in cycles per second or Hertz) and 2) amplitude (measured in microvolts). Butler and Glass (1976) describe the ongoing EEG as follows:

> By "ongoing" EEG is meant the continuously varying voltage recordable between pairs of electrodes on the head in the frequency band 0-30 Hz. For descriptive purposes the ongoing EEG is usually subdivided into a number of smaller frequency bands, each encompassing rhythms characteristic of different behavioral states. Thus delta rhythm (1-3 Hz) typically occurs during sleep, alpha rhythm (8-13 Hz) during relaxed wakefulness, beta rhythm (frequencies greater than 13 Hz) during periods of intense mental activity, while theta rhythm (3-7 Hz) is often found when the brain is developing. Activity in the alpha frequencies has so far provided the most interesting information in connection with asymmetries of cerebral function (pp. 220 - 221).

The EEG has been used to infer the differential involvement of each cerebral hemisphere during various cognitive activities. Accordingly, the usual experimental procedure for inferring differential involvement of each hemisphere from EEG data recorded during cognitive activities is to place electrodes on various sites of each hemisphere and then ask the subject to perform verbal and nonverbal tasks while the EEG is recorded. Donchin et al.(1977) state:

> One promising paradigm involves the comparison of the distribution of spectral power in the alpha band at homologous hemispheric locations while subjects are engaged in tasks presumed to differentially engage the hemispheres. This interest derives from the earliest studies of the EEG by Berger (1930) and Adrian and Matthews (1934) which indicated an inverse relationship between alpha presence and 'mental effort'. The assumption is made that hemispheric involvement is indexed by differential suppression of alpha. The hemisphere more engaged in the task would exhibit less alpha activity than the idle hemisphere (p. 214).

Therefore, if the left hemisphere is specialized to process linguistic information, at least in right-handers, then one would expect to record less alpha during verbal tasks from the left hemisphere than from the right hemisphere. One would also expect to record less alpha from the right hemisphere than from the left during nonverbal activities; that is, if the right hemisphere is specialized to process nonverbal information. Some findings from a number of EEG experiments on normal subjects will be presented.

Experimental research using the EEG has been done on infants, children, and adults to investigate hemispheric specialization. Gardiner and Walter (1977) presented verbal and musical stimuli to four infants aged 6 months. They placed electrodes over the left and right parietal (P_3, P_4) and temporal (W_1, W_2) areas on the surface of each infant's skull to record EEG power distributions during the presentation of verbal and musical stimuli. Analysis of EEG activity was done on frequency bands in the vicinity of 4 Hz. Gardiner and Walter found that "in all 4 infants, parietal and Wernicke pairs (where available) exhibited reduction in the proportion of left hemisphere to total bihemispheric power for speech relative to music, in the activity near 4 Hz (p. 492)." They conclude that their results "... fail to support Lenneberg's (1967) theory of gradual development of lateralization of function but instead give added support to recent findings, both from patients and normal subjects, that suggest that some functional asymmetries may already be present in the normal human brain at, or soon after birth (p. 495)." This conclusion is similar to that made by Entus (1977) who found a right-ear advantage to speech (dichotic listening) in infants aged 3 months.

An excellent summary on the relationship between alpha waves and cognitive activity is stated in the introduction to a study conducted by Cole and Cummings (1977). They state the following:

> When humans are relaxed, drowsy, or in meditative states, the EEG typically reveals a predominance of alpha waves having a frequency between 8 and 12 Hz. If a subject in this state is given a problem

> to solve, the alpha waves are replaced by asynchronous beta waves having a frequency greater than 12 Hz. The percentage of alpha rhythm may thus be used as a rough measure of the amount of ongoing information processing at a particular cortical location. The more alpha rhythm that is present, the less ongoing information processing is assumed to be occurring. Based on our present knowledge of cerebral specialization of function, we should expect to find less alpha rhythm in the left hemisphere during linguistic tasks than during spatial tasks, while the opposite pattern should occur in the right hemisphere (p. 37).

Cole and Cummings (1977) empirically tested this expectation by recording EEG alpha rhythms from the left and right frontal and temporal locations of 35 normal right-handed children (aged 3 - 6 years old) during the presentation of verbal (stories) and nonverbal (cartoon movie) information. They found that children produced more alpha in the left hemisphere while watching a cartoon than when listening to a story -- an effect which was as strong for the 4 year olds as it was for the 6 year olds (p. 41). The experimenters conclude that their results "... suggest that there is an increase in left hemisphere alpha rhythm -- presumably indicating a decrease in information processing in that hemisphere -- when 4- to 6-year-old children observe a cartoon, as compared to their left hemisphere alpha rhythm when listening to a story (p. 45)." A similar pattern of results was not obtained from the right hemisphere. One difficulty with this study is the nature of information processing associated with the cartoon. That is, children may covertly associate verbal labels with the visual presentation of the cartoon. Hence, the difference between the two stimuli may be simply a difference between auditory (story) and visual (cartoon) sensory stimulation.

Morgan et al. (1971) compared the alpha activity in the left and right occipital lobes of 20 right-handed adults during analytic and spatial activities. The analytic condition consisted of 9 tasks (e.g. add 16 and 18, recite a few lines of a poem) and the spatial condition consisted of 5 tasks (picture a child swinging on a swing, imagine you are watching a ballet). Morgan et al. found that, compared to the left hemisphere 19 of the 20 subjects displayed more alpha activity in the

right hemisphere during the analytic condition and 16 of the 20 subjects displayed less alpha in the right hemisphere during the spatial conditions. That is, the right hemisphere was less active than the left during the analytic condition and more active than the left during the spatial condition. Using different tasks and recording from different locations (left and right parietal and temporal), McKee et al. (1973) found similar results. McKee and his associates used three linguistic tasks of varying difficulty and a musical task in an experiment with four right-handed subjects. They found the largest L/R (left divided by right) alpha ratio for the music task and successively smaller L/R alpha ratios for increasingly difficult linguistic tasks. Interestingly,both of the above studies found more alpha activity over the right than over the left hemisphere regardless of task.

The hypothesized relationship between alpha production and task asymmetry (i.e. less alpha in the left hemisphere during verbal tasks and less alpha in the right hemisphere during spatial tasks) has been found in studies conducted by Galin and Ornstein (1972); Doyle, Ornstein, and Galin (1974); and Furst (1976). These studies used normal right-handed adults as subjects. In addition, Galin and Ornstein (1972) and Doyle et al. (1974) discovered that lateral asymmetry was strongest in the alpha band and for verbal and spatial tasks involving motor activity. Furst (1976) found that subjects with lower R/L alpha ratios (less alpha in the right hemisphere) solved visuospatial problems more efficiently. That is, subjects who activate the right hemisphere to a greater extent than the left perform better on a right hemispheric task. Amochaev and Salamy (1979) and Erlichman and Wiener (1979) did not find conclusive results regarding proposed hemispheric asymmetry but both experiments did show a moderate amount of reliability in task-related EEG asymmetries over time. Finally, in an experiment conducted by Gevin et al. (1979), subjects (right-handed adults) displayed EEG asymmetry to verbal and spatial tasks but the experimenters suggest that observed EEG asymmetry results from inter-task differences in efferent activity, stimulus characteristics, and performance-related factors rather than from true differences

in cognitive processing. In order to determine EEG asymmetry of verbal and nonverbal tasks, such confounds as pointed out by Gevins and his associates must be controlled. Other confounds could be instrumental or physiological (Shagass, 1972). Thus, EEG frequency analysis is an informative/exciting technique but it does have limitations, as well.

Evoked Potential Studies

Evoked potentials, another electrical measurement of the brain, have been used in a number of experiments to assess hemispheric asymmetry. Typically, evoked potential (EP) or event-related potential (ERP) studies record the amplitude (power) and latency (time) of the brain's electrical activity in response to a repeated stimulus (visual, auditory, or somatosensory). According to Marsh (1978):

> Another electrophysiological phenomenon that can demonstrate hemisphere asymmetry is the electrical activity elicited by presentation of stimuli. This activity is generally of smaller magnitude than the ongoing EEG activity and must be extracted from the scalp-recorded EEG by summing together several short portions (e.g. 500 milliseconds) of the EEG record following several stimulus presentations. Random portions of a normal, unstimulated EEG record tend to sum to zero because the varying electrical activity is not tied to any one specific external or internal event. However, when just the portions of the EEG time-locked to the repeated presentation of a stimulus are summed, the electrophysiological responses elicited by the stimulus are accumulated, and the electrical events not tied to the stimulus tend to cancel toward zero (pp. 300 - 301).

With respect to hemispheric specialization, attempts have been made to determine whether verbal and nonverbal stimuli evoke different responses in the left and right hemispheres (Butler and Glass, 1976).

Again, evoked potential studies on normal infants, children, and adults have attempted to determine if and how the two cerebral hemispheres are specialized to process information. In general, several studies have found that evoked potentials from the left hemisphere are higher in amplitude during verbal tasks and that evoked potentials from the right

hemisphere are higher in amplitude during nonverbal tasks (Butler and Glass, 1976; Neville, 1978). The inference made is that there is a direct relationship between the amplitude of evoked potentials and cerebral activation. If such a relationship exists between verbal tasks and the left hemisphere and between nonverbal tasks and the right hemisphere, these results are taken as evidence of hemispheric specialization. Some specific studies will now be reviewed.

Molfese (1977), presented verbal (syllables -- ba, da; words -- bye, dog) and nonverbal (musical chord, burst of noise) stimuli to 10 infants aged 1 week to 10 months, 11 children aged 4 to 11 years, and 10 adults aged 23 to 29 years. Evoked potentials were recorded from the left and right temporal regions of the brain. During speech sounds, greater amplitude of auditory evoked potentials (AEP) was found in the left hemisphere of 27 of the 31 subjects. During the presentation of the musical chord, the AEP was greater in amplitude for the right hemisphere in 30 of the 31 subjects. Molfese found that "... the degree of laterality in the infants was actually greater than that of adults for both the speech and nonspeech stimuli (p. 23)." He concludes that, at least, "... some degree of hemispheric specialization appears to be present in human infants long before the age of 2 years suggested by Lenneberg (p. 25)." Such a conclusion is shared by others(Entus, 1977; Gardiner and Walter, 1977).

Switching to EP studies on adults, Matsumiya et al. (1972) found that the proposed hemispheric asymmetry may relate more to the meaningfulness of the stimuli than to verbal versus nonverbal differences. They found the largest asymmetry when the subjects (9 right-handed adults) maximally attended to meaning. Meaningfulness is an important matter to consider since many so called right hemispheric tasks are nonmeaningful. Galin and Ellis (1975, 1977) compared results from evoked potential analyses with those from EEG alpha analyses. They found that "... overall power and peak amplitude characteristics of evoked potential asymmetry reflect the lateralization of cognitive processes, but not as consistently

as the concomitant asymmetry in EEG alpha power (Galin and Ellis, 1975, p. 48)." Finally, Kutas and Hillyard (1980) presented seven word sentences, one word at a time (flashed for 100 milliseconds), to nine right-handed adults. All but the first word in the sentence elicited an event related potential (ERP) with a significant left-greater-than-right assymmetry in the late positivity (400 to 700 milliseconds after stimulus onset) over temporo-parietal (Wernicke's area) regions (p. 354). However, according to Kutas and Hillyard, it is important to note that such results may be a "... reflection of the specific engagement of language systems in the left hemisphere... [or] ... it may be the extraction of meaning rather than the linguistic analysis per se ... (p. 365)."

The evoked potential procedure is not without limitations. First, since evoked responses are highly subject to habituation, repeated presentation of stimuli may result in a considerable attenuation of the response (Shagass, 1972). Of course, this problem can be overcome by presenting novel stimuli. Secondly, various bioelectric sources of artifact can influence asymmetrically speach-related electrical potentials -- eye movements, GSR, head movements, muscle tension, respiratory waves, and lip and tongue movements (Donchin et al. 1977). And thirdly, as with EEG frequency studies, meaningfulness of the stimuli may obscure the asymmetry presumed to result from verbal and nonverbal tasks.

Regional Cerebral Blood Flow (rCBF) Studies

Another technique that has been used to measure the differential involvement of each cerebral hemisphere during information processing is the regional cerebral blood flow (rCBF) technique. Briefly, the physiological basis of the rCBF technique is that increased neuronal activity requires an increase in oxygen which is supplied to cortical areas by blood. Hence, more blood is required by a particular cortical area that is relatively more active than another area (Ingvar, 1978; Lassen et al., 1978). The procedure involves a number of steps:

1. a radioactive isotope (e.g. 133 Xenon) is injected or inhaled by the subject,

2. the subject is engaged in a neural act (speech, reading, listen to noises),

3. detector probes are placed on various areas of the skull and they transmit information to a gamma-ray camera,

4. cerebral activity (various colors depict varying levels of blood flow) is displayed on a color television screen.

Hence, the dependent variable is the relative amount of blood flow in a particular cortical area. On the basis of prior knowledge from studies of hemispheric specialization, one would expect to monitor greater levels of blood flow in the left hemispheric language areas (Broca and Wernicke's areas) during verbal information processing and greater levels of blood flow in the right hemisphere during spatial or nonverbal information processing. This expectation has been tested in a number of studies using normal right-handed adults as subjects.

In an experiment conducted by Risberg et al. (1975), 24 right-handed normal adults participated in the rCBF procedure. All 24 subjects were paid $20.00 for participating but 12 of the subjects (Reward group) were promised additional money based on their performance on verbal and spatial tests. Regional cerebral blood flow was measured during three conditions -- resting, verbal test (Miller's Analagies), and a spatial test (Steet Test -- perceptual closure). The recorded blood flow to each hemisphere was similar during the resting condition. During the verbal task blood flow increased by 16% in the left hemisphere and 13% in the right. And during the spatial task blood flow increased by 7% in the left hemisphere and 10% in the right. These figures pertain to the Reward group only. The other 12 subjects showed a similar pattern but not to the same degree as the reward group. In addition, Risberg et al. found that "... the largest inter-hemispheric differences (about 5%) were seen in occipital and parietal regions during the verbal test and in frontal and parietal

regions during the spatial test (p. 523)." The small but statistically significant differences between the blood flow in the left and right hemispheres show that the left hemisphere is more actively involved in processing verbal information and the right hemisphere is more actively involved in processing spatial information.

Gur and Reivich (1980) used the same tasks as Risberg et al. (1975) in a rCBF experiment on 36 normal right-handed adults. They found a significant increase in left relative to right hemisphere flow during the performance of the verbal task and an increase in right relative to left hemisphere flow during the performance of the spatial task (p. 86). Gur and Reivich found that greater increase in blood flow to the right hemisphere was associated with better performance.

In a study by Knopman et al. (1980) it was found that "an increase in rCBF in the posterior perisylvian area on the left occurred with both verbal and nonverbal activation (p. 103)." But this experiment required subjects to use a motor response (push a button with the right forefinger) to both verbal and nonverbal tasks. The verbal condition required the subject to pick out words that meant "something to eat" from a list of nouns. For the nonverbal condition, subjects had to distinguish the softer sound from two noise bursts. Since all subjects were right-handed, the motor act of using the right hand to signal answers to both conditions may be a confound and, thus, explain increased blood flow to the contralateral (left) hemisphere.

Notwithstanding, the rCBF technique appears to be a valuable tool in investigating hemispheric specialization of normal and clinical populations. Ingvar (1978) states that "the EEG technique, and to some extent also evoked potentials methods, as well as rCBF measurement, represent different ways of recording mass activity distribution in the brain. Combined, such studies may, it seems, help us to understand the global functions of the brain, including those which relate to mentation (p. 79)."

The studies on cerebral functional asymmetry reviewed above (dichotic listening, tachistoscopic presentation, EEG frequency analysis, evoked potential, and rCBF) tend to suggest that, at least in right-handed adults, the left hemisphere is more specialized to process verbal information than the right and the right hemisphere is more specialized to process nonverbal information than the left. In addition, some studies were reviewed that show the left and right hemispheres to be morphologically dissimilar, especially in regions believed to subserve verbal information processing. Hence, it is proposed that a model of hemispheric specialization seems to be substantiated by empirical research on normal right-handed adults. Controversy with respect to the onset of hemispheric specialization exists in the research literature and merits further discussion.

The Onset of Hemispheric Specialization

The two extreme positions on the onset of hemispheric specialization are:

1. the two hemispheres are completely specialized at or prior to birth, and

2. hemispheric specialization is a continuous process throughout the life span.

Intuitively, the former position seems less tenable. To explain, well-known theories in developmental psychology (e.g. Piaget, Bruner) suggest that a child's cognitive development progresses through a number of stages -- each stage more complex than the former. Also, it seems illogical to assume that an infant's brain is completely specialized to subserve tasks that it cannot yet perform. And since an infant is not capable of performing complex cognitive tasks, the first position can probably not be empirically tested.

It is known, however, that the two hemispheres of the infant brain are dissimilar in structure (Wada et al, 1975; Witelson and Pallie, 1973) and in function (Entus, 1977; Gardiner and Walter, 1977; Molfese, 1977). Perhaps these studies show that hemispheric specialization is present at birth but they do not show that hemispheric specialization is complete at birth. Moscovitch (1977) states the following:

> "... although the evidence presented in this chapter favors the notion that hemispheric differences in structure and function are apparent very early in development, it does not follow that the process of lateralization is complete at this early stage (p. 206).

Moscovitch (1977) then presents two alternatives regarding the development of language lateralization:

1. a process of gradual lateralization in which low-level linguistic functions (phonetic or phonological) are lateralized by the first year of life and as a child's linguistic and cognitive skills develop, language becomes more strongly lateralized to the left hemisphere, or

2. syntactic and semantic functions are completely lateralized by the time a child utters his first words and experience/maturation affect only the development of language in the left hemisphere, but not the process of lateralization (pp. 206 - 207).

According to Moscovitch, the answer to this dilemma has not yet been found although Moscovitch, himself, seems to prefer the former explanation.

Another view is proposed by Kinsbourne (1975) who states that "cerebral dominance does not develop; it is there from the start. Thus, one could hardly relate the excellence of language behavior to such a development nor sensibly seek for measures which would accelerate that non-existent process (pp. 248 - 249)." He reviews literature on this subject and further develops his rationale in later works (Kinsbourne, 1978; Kinsbourne and Hiscock, 1977). Kinsbourne is not convinced that there is neuropsychological evidence or evidence from the ontogeny of asymmetry in normal behavior that validates the concept of developing lateralization. On the other hand, Brown and Jaffe (1975) cite clinical and experimental evidence that, they think, supports the developmental view of hemispheric specialization. They state that "the evidence cited is in support of the hypothesis that cerebral dominance is not a state but a process, and one that continues through life (p. 108)." These are the two extreme positions mentioned earlier. Is there a resolution to this issue?

Perhaps, at this time, there is not a final resolution but certain questions are nearer an answer. For example, the equipotential hypothesis (both hemispheres are likely candidates to develop language specialization) seems to be in disfavor. According to Dennis and Whitaker (1977):

> Hemispheric equipotentiality does appear to make an untenable supposition about the brain because it neither explains nor predicts at least two facts about language -- that the two perinatal hemispheres are not equally at risk for language delay or disorder and that they are not equivalent substrates for language acquisition (p. 183).

Also, the two hemispheres of infants are dissimilar regarding structure and function. Or, as stated by Joynt (1975), "it does seem that there is biologic preprogramming for language and that hemispheric specialization is part of our heritage (p. 52)." Equipotentiality would argue strongly for the development of hemispheric specialization after infancy.

In addition, one must be cautious in interpreting perceptual asymmetry studies (e.g. dichotic listening) which show an increasing lateralization with age. Certain other factors may be confounds -- attention, type of stimuli (phonemic, syntactic, semantic), memory, or levels of processing (Bryden & Allard, 1978; Porter & Berlin, 1975). The dichotic studies that found increasing asymmetry with increasing age (Davidoff et al., 1978; Satz et al., 1975) presented in the present review used either two dichotic consonants or digit pairs as stimuli. One would expect such tasks to be specialized at a very early age (Bryden & Allard, 1978). Other studies discussed here failed to show a significant increase of asymmetry with increasing age (Cole & Cummings, 1977; Molfese, 1977). The main point here is that there may not exist strong evidence in favor of the extreme developmental lateralization point of view. However, neither extreme position can be rejected on the basis of present knowledge.

As a result, it may be wiser to look for other alternatives and continue to, if possible, empirically test each possibility. A final point-of-view is proposed by Witelson (1977a). Her proposal lies somewhere between the two extremes. Briefly, she suggests that both functional specialization and hemispheric plasticity coexist at birth. But she does state that biological pre-programming for language may limit plasticity to some degree. Witelson (1977a) summarizes her view as follows:

> Left hemisphere specialization may be functional at birth, similar to Kinsbourne's (1975) suggestion, but this does not necessarily mean that it remains unchanged from infancy to senescence. The present view is that as a cognitive function develops which requires the type of processing for which the left hemisphere is specialized, then that cognitive function and any tasks dependent on such functions will be processed more by the left than the right hemisphere. In this view what develops primarily is the extent of the child's cognitive repertoire, and as more functions are available to be processed predominantly by the left hemisphere, they are. Thus, with development, left hemisphere specialization comes to encompass a broader scope of skills for which its particular cognitive mode of sequential, analytic, linguistic processing is particularly suited. In some sense, then, left hemisphere specialization does increase, but only indirectly, as a secondary manifestation of cognitive development (p. 269).

Such a moderate theory is attractive but it also requires empirical validation. The stance taken for the present review is that hemispheric specialization is probably present at birth but further research is needed to suggest either that hemispheric specialization is complete at birth or that it develops according to cognitive development. This issue will again be discussed in later sections of the present review.

DESCRIPTIVE FEATURES OF CHILDREN HAVING DIFFICULTY LEARNING TO READ

The focus of the present section of the literature review is on descriptive features of children who have difficulty learning to read as compared to those who do not encounter difficulty in learning to read. The Eisenberg (1966) definition generally characterizes the research population considered here -- "Specific reading disability may be defined as the failure to learn to read with normal proficiency despite conventional instruction, a culturally adequate home, proper motivation, intact senses, normal intelligence, and freedom from gross neurological defect (p. 360)." In general, a similar population has been variously referred to as learning disabled (Gaddes, 1980), learning disordered (Knights and Bakker, 1976), dyslexic (Benton and Pearl, 1978; Vellutino, 1979), reading disabled (Tarnopol and Tarnopol, 1977), reading disordered (Pirozzolo, 1979) and specific reading retardation (Rutter, 1976). For the purposes of the present review, a preferred label would be "reading difficulty."

The following description of children with reading difficulty will begin with a discussion on models of reading disability. Next, some general features of reading difficulty will be examined. Some researchers propose that it is important to consider neurological aspects of reading disability, at least, for some types of problem readers. This claim and other issues related to neurological aspects of reading difficulty will be reviewed. Finally, developmental aspects of reading difficulty will be considered.

Models of Reading Disability

Two conceptualizations regarding models of reading disability will be reviewed -- Guthrie (1973) and Applebee (1971) -- as a context for forthcoming information. Guthrie (1973) proposes two models of reading that are implicit in reading research and then he presents empirical information which confirms one of the two models. Guthrie describes the two models as follows:

> The first model proposes reading to be an assembly of independent components (assembly model). The components are independent since they may exist in high or low degrees of strength for a given individual. The only relationship among the components is that they must occur or be capable of occurring in close succession during the act of reading ... According to this model, children develop the abilities of auditory discrimination, visual discrimination, auditory memory, visual memory, and word meaning independently. In poor readers, one of these abilities fails to develop normally, and the child's reading is impaired as a consequence of the one specific deficit, although the other abilities may develop to normal levels of strength ... The second model views reading as a system of associated components (system model). This model suggests that the reading process requires the presence of components that are not identical in function or strength but that are interdependent. For a given individual, these components may have different degrees of strength but do not increase in strength more rapidly than the component with the slowest growth rate (p. 10).

Hence, a low intercorrelation of subskills in normal readers would confirm the assembly model while a high correlation of subskills in normal readers would confirm the system model. As a result, one would expect disabled readers to be deficient on a small minority of subskills according to the assembly model and disabled readers would exhibit deficiency in a large majority of subskills according to the system model (pp. 11 - 12).

Guthrie (1973) found that disabled readers and normal readers matched on I.Q. and reading level were similar in the strength of subskills but both groups were inferior to the normal readers who were matched on I.Q. and age with the reading disabled group. In addition, the intercorrelations of subskills were high positive for both normal reading groups and

largely insignificant for the reading disabled group. As a result, Guthrie concludes that the system model is confirmed and, further, that "one source of disability for poor readers is lack of integration and interfacilitation among subskills (abstract, p. 9)."

Another conceptualization on models of reading disability is proposed by Applebee (1971). He presents six possible models of reading disability. Briefly, the models are as follows (Applebee, 1971 pp. 99 - 110):

MODEL 1: A single causal defect -- poor readers represent a homogenous population deficient in a single ability essential in learning to read. No one has been able to produce data which conform to this model.

MODEL 2: Several independent causal effects -- this is similar to Model 1, but it allows for the possibility of a number of "critical" abilities necessary for reading, the lack of any one of which would be sufficient to cause the disorder. This model comes closer to explaining research results than Model 1.

MODEL 3: Multiple regression with one functional relationship -- reading achievement, according to this model, is a simple additive function of the level of each of the factors involved, described by a multiple regression equation. One assumption of this model is that the same set of variables will distinguish between good, average, and poor readers.

MODEL 4: Multiple regression with several functional relationships -- reading disability can be explained in terms of additive functions of the factors involved, but there are two or more regression equations functioning within the same sample. For example, regression parameters would be different for boys and girls, for different age groups, or for different social classes. In general, regression models better explain the relative position of individuals within the middle range of achievement than that of severe reading disabled individuals.

MODEL 5: Disorder dependent on pattern of factors -- reading disability is a homogenous disorder and depends on an interaction of relative status on various factors. For example, a reading disabled individual might be poorer in auditory memory than visual memory rather than have an absolute deficit. This model provides no expectation about differences between good and poor readers regarding the absolute levels of various abilities.

MODEL 6: Several independent disorders dependent on patterns of factors -- reading disability can be caused by any of several relevant and independent patterns of factors.

According to Applebee (1971), some retarded readers may best be explained by Model 4, for example, while other problem readers might be explained by Model 2 or 6. It might be best to start with the simplest explanation and move towards more complex models, if necessary (p. 111). However, it is necessary to concentrate on new models which correspond more closely to the heterogeneity of reading disability. In order to do this, sophisticated methods of data analysis (e.g. cluster analysis, profile analysis) are required. Finally, Applebee suggests that past research has shown that the simplest models do not fit the problem of reading disability.

Both Guthrie and Applebee propose possible models of reading disability. Guthrie prefers a model which emphasizes a system approach with respect to reading ability and disability. That is, according to Guthrie, it is important to look at how reading subskills <u>interact</u> in understanding reading disability. For Applebee, it is important to view reading disability as a heterogeneous disorder and to, perhaps, reject models which do not fit the population under study. The complexity of the disorder may require a number of models which assume heterogeneity in order to describe the population under study.

General Features of Reading Difficulty

To further the description of children with reading difficulty, various perspectives on the disorder will be presented. First, the verbal deficit hypothesis (F.R. Vellutino) deserves mention. Secondly, according to M.D. Vernon, there is variability in reading retardation. Such a claim will be examined next. Thirdly, a discussion on some of the various subgroups of reading difficulty will follow. After discussing these general features of reading difficulty, some more specific aspects (i.e. neurological and developmental) will be reviewed.

The Verbal - Deficit Hypothesis

Vellutino (1977, 1978, 1979) argues in favor of a verbal-deficit hypothesis in characterizing reading disability. In the introduction to his recent book, _Dyslexia: Theory and Research_, Vellutino (1979) states the following:

> ... my own laboratory studies and practical experience, the research of independent investigators studying normal and abnormal reading and language abilities, and some degree of intuition strongly suggest that a most promising but relatively unexplored avenue for additional study inheres in the possibility that specific reading disability is caused either by dysfunction in verbal processing or by a specific deficit in visual-verbal integration. I am inclined to agree with those who contend that reading is primarily a language-based skill, as illustrated in the fact that three of the five types of featural information contained in a printed word (graphic, orthographic, semantic, syntactic, and phonological) correspond with the major components of language. Thus the ability to learn to read would appear to be especially vulnerable to deficiencies in one or more of these linguistic functions, though perhaps not in equal measure (p. 4).

An examination of Vellutino's arguments which lead him to propose the verbal-deficit hypothesis will clarify his position.

Vellutino (1977) presents an overview of the literature on reading disability. In this article, he critically examines four explanations

for reading failure in children: 1) deficiency in visual processing, 2) deficiency in inter-sensory integration, 3) dysfunction in temporal-order perception, and 4) deficiencies in verbal processing. Briefly, Vellutino's arguments against the first three explanations are as follows:

> 1. Visual processing deficiency: the orientation and sequencing errors believed to be classic indicators of visual-spatial confusion in poor readers can be more plausibly interpreted as secondary manifestations of verbal-mediation difficulties (p. 347),
>
> 2. Inter-sensory integration deficiency: there is persuasive evidence that the deficiencies observed in poor readers on tasks thought to be measuring cross-modal transfer may have been due to difficulties in verbal encoding (pp. 347 - 348), and
>
> 3. Temporal-order perception dysfunction: a plausible alternative explanation of reader-group differences in ordered recall is dysfunction in verbal processing (p. 341).

Regarding verbal processing deficiencies, Vellutino (1977) states that "...poor readers neither code (label) nor synthesize (chunk) information for effective storage and retrieval as readily as average readers because of problems in one or more aspects of language (p. 341)." According to Vellutino (1977, p. 348), the aspects of language which may be deficient in poor readers are semantic (linguistic coding and retrieval of information), syntactic (deficiencies in grammatical competence), and phonological (grapheme-phoneme correspondence). This then is Vellutino's explanation of reading disability.

Variability in Reading Difficulty

In a review of recent research on reading disability, Torgesen (1975) discusses studies on deficiencies related to visual-perceptual functioning, perceptual motor functioning, memory functions, verbal abilities, intermodal integration, learning ability and attention. He then states that "perhaps the strongest conclusion from the preceding review is that the reading-disabled population of children may be differentiated from those who learn normally on a broad variety of performance measures (p. 412)."

Vernon (1977, 1979) would agree since she suggests that reading disability is not a unitary phenomenon.

As proposed by Vernon (1977, 1979), good research in grouping poor readers according to deficiencies would take into account the various steps required in learning to read. In her 1979 article she suggests that reading involves the acquisition of a succession of skills and that different types of retarded readers may be classified according to deficiencies displayed at different stages in the acquisition of reading skills as outlined below:

1. analysis of complex visual shapes,
2. analysis of whole-word sounds into phonemes,
3. making simple regular grapheme-phoneme associations,
4. grasping irregularities in grapheme-phoneme associations, and
5. grouping single words into phrases and sentences.

This conceptualization of reading disability is in accordance with clinical and experimental work that delineates various subtypes of problem readers. Empirical research on subgroups of reading difficulty is the next topic for discussion and will conclude the section on general features. Three of these studies will be reviewed.

Subgroups of Problem Readers

According to Boder (1971), "... developmental dyslexia is diagnosed in one or more of the following ways: (1) by a process of exclusion, (2) indirectly, on the basis of its neurological or psychometric concomitants, (3) directly, on the basis of the frequency and persistence of certain types of errors in reading and spelling (p. 294 - 295)." The diagnostic approach Boder uses is an extension of direct approaches and an approach which demonstrates that children with developmental dyslexia are heterogeneous, etiologically and clinically. On the basis of

diagnostic reading-spelling patterns, Boder classified children with developmental dyslexia into the following three subgroups (p. 299):

> GROUP 1. Dysphonetic Dyslexia - Reading-Spelling pattern reflects primary deficit in symbol-sound (grapheme-phoneme) integration and in the ability to develop skills in phonetic word analysis-synthesis.
>
> GROUP 2. Dyseidetic-Dyslexia (Gestalt-blind) -- Reading-spelling pattern reflects primary deficit in the ability to perceive letters and whole words as configurations, or visual Gestalts.
>
> GROUP 3. Mixed Dysphonetic-Dyseidetic Dyslexia (Alexia) -- Reading-spelling pattern reflects primary deficit both in ability to develop phonetic word-analysis skills and ability to perceive letters and whole words as visual Gestalts.

Characteristic reading-spelling patterns of each subgroup are described by Boder (1971, pp. 301 - 308).

For example, dysphonetic dyslexic children read words globally rather than analytically and when they confront words that are not in their sight vocabulary they may guess the word from contextual cues but do not sound out or blend letters and syllables of a word. Dysphonetic dyslexic children spell by sight alone and not by ear. Typical reading-spelling errors may be termed semantic-substitution errors: "funny" for "laugh", "home" for "house", or "human" for "person". Dyseidetic children read analytically and by ear sounding out combinations of letters. Their reading can be laborious and choppy. Dyseidetic spellers spell by ear but since their misspellings are phonetic, the original word can usually be identified. Thus, they may write "laf" for "laugh", "burd" for "bird", or "onkl" for "uncle". And mixed dysphonetic-dyseidetic dyslexics are the most severely handicapped of the three subgroups. They cannot read on sight or by ear. Characteristically these children are both nonreaders and nonspellers. Their misspellings appear bizarre. From a sample of 107 dyslexic children (8 - 16 years old), Boder found that 63% were dysphonetic, 9% were dyseidetic, and 22% were mixed dyslexics. Concerning remedy, Boder states that "... these three patterns

-- because they reflect functional assets as well as deficits in the central visual and auditory processes prerequisite to reading -- have prognostic and therapeutic implications, differing for each of the three subtypes (p. 319)." Aaron (1978) provides empirical support for Boder's classification.

Another categorization of reading disabled children is proposed by Mattis, French, and Rapin (1975). They also suggest that children with severe reading problems have differing patterns of deficits in higher cortical function. As stated by Mattis et al. (1975):

> The underlying assumption is that if the development of fluency in reading requires the complex integration of several input, output, and mediating processes, then a deficit in any given critical process would impair the learning of this complex skill. There should therefore exist separate subgroups of dyslexic children who manifest differing clusters of deficiencies, each of which limits the development of a specific sub-process necessary for the acquisition of reading skill (p. 151).

To test such an assumption Mattis et al. conducted a study which included an examination by a pediatric neurologist and the administration of an extensive battery of neuropsychological tests.

The sample selected for the Mattis et al. (1975) study included 113 children (8 - 18 years old). They divided the children into three groups: those with brain damage who could read (n = 31), those with brain damage who were dyslexic (n = 53), and those without brain damage who were dyslexic (n = 29). Mattis et al. (1975) found that the developmental dyslexic and the brain-damaged dyslexic were very similar on the measures used in the study. In addition, they found three separate patterns of deficits in the dyslexic sample: 1) language disorder, 2) motor-speech difficulty, and 3) visual-spatial perceptual disorder. The separate syndromes (accounted for 90% of the dyslexics) were described as follows (p. 155, 157):

1. Language disorder -- these children had a lower verbal than performance I.Q. and obtained the lowest reading and arithmetic scores of the three groups. As a group, these children had normal visuo-perceptual, graphomotor, and speech blending abilities. Forty-three percent of the brain-damaged dyslexics and 28% of the developmental dyslexics were classified in this group.

2. Speech and graphomotor dysco-ordination -- children classified in this group had only slight differences between verbal and performance I.Q. Reading and arithmetic scores were somewhat higher than those found in the other two groups but spelling was lower. Language functioning and visual perception were intact. Thirty percent and 48% of the brain-damaged and developmental dyslexics were classified in this group, respectively.

3. Visual-perceptual disorder -- children in this group scored lower on the Raven's Coloured Progressive Matrices Test than the performance I.Q. of the WISC. These children were also deficient on the Benton Test of Visual Retention. This group was composed of the smallest number of children -- 17% of brain-damaged dyslexics and 14% of developmental dyslexics.

According to Mattis et al. (1975), "the results support a model of dyslexia as being caused by multiple independent defects in higher cortical functioning, as opposed to a theory of a single causal defect (p. 161)."

A third study (Lyon and Watson, 1981) on empirically derived subgroups of learning disabled readers used a cluster analysis procedure to identify subgroups of children in terms of performance on a battery of eight language and perceptual tests. There were 100 specific learning disabled and 50 normal readers tested in this study. Of the 100 disabled readers, 94 were classified into six distinct subgroups. These subgroups are described by Lyon and Watson as follows (p. 260):

1. Children in subgroup 1 (11%) displayed deficits in language comprehension, auditory memory, sound blending, visual-motor integration, visual-spatial and visual-memory skills. These children are like Boder's (1971) mixed dysphonetic-dyseidetic dyslexics.

2. The mixed deficits exhibited by subgroup 2 (13%) in language comprehension, auditory memory, and visual-motor integration skills corresponds to a mild form of Boder's (1971) combined dysphonetic and dyseidetic dyslexic.

3. The problems manifested by subgroup 3 (13%) in language comprehension and sound blending indicate a language disorder with both receptive and expressive components. Children in this subgroup are similar to the language disorder group described by Mattis et al. (1975) and the dysphonetic dyslexic group identified by Boder (1971).

4. Reading impairments of children in subgroup 4 (34%) are due to deficiencies in visuoperceptive capacity rather than language-based deficiencies. This subgroup resembles Boder's (1971) dyseidetic dyslexic and Mattis et al.'s (1975) visual-perceptive dyslexic group.

5. Children in subgroup 5 (13%) had deficits in retention, synthesis, and expression of sound and word sequences. They were poor at remembering and sequencing auditory information.

6. The pattern of scores obtained by members in subgroup 6 (17%) indicates a normal diagnostic profile. Perhaps social, motivational, or pedagogical factors account for reading difficulty in this subgroup.

One area that needs more research, according to Lyon and Watson, is that on the stability or instability of subgroup patterns across age groups. The developmental aspects of reading disability will be discussed later.

Considered together, the three studies above make a strong case for matching treatment with the specific pattern of deficits displayed by a particular subgroup of reading disabled children. Dalby (1979) states that "... the identification of patterns of abilities is not only essential for individual remediation but is the keystone to neuropsychological investigations (p. 242)." Many studies which attempt to define subgroups of reading disability use neuropsychological test batteries for that same purpose. Neurological aspects of reading disability is the next topic for discussion.

Neurological Aspects

A complete or thorough description of children with reading difficulty would include findings from neurological or neuropsychological research. Gaddes (1980) takes this one step further:

> No one theory is complete or necessarily valid, but the best available knowledge should be used to develop a theory constantly open to review and revision in light of new experimental evidence. Similarly, no one remedial practice is appropriate for treating all behaviour or learning problems. For the child with a serious or subtle learning disorder, neuropsychological diagnosis for understanding the nature of the child's problem, and behaviour management techniques for treating it, are probably the best at this point in our knowledge (p. 15).

The stance taken here is that neurological aspects of reading disabled children can no longer be ignored. That is, as stated by Gaddes (1980), "to view the learning disabled child scientifically and objectively we cannot afford to exclude any area of tested knowledge or any form of remediation that promises possible help to the child (p. 323)." After reviewing various issues and problems facing researchers who study and interpret brain influences in reading disabilities, Dalby (1979) concludes that "there is sufficient evidence to implicate atypical brain function as a source of reading difficulties in children with normal intelligence (p. 257)." The main purpose here is to highlight information from research on neurological deficits associated with reading difficulty.

According to Benton (1975), "conceptions of the basic abnormality underlying developmental dyslexia fall into two broad categories: those that postulate a focal maldevelopment of the brain, and those that emphasize a defect in the overall organization of cerebral function (p. 31)." The focal maldevelopment theories have, in the past, implicated the cerebral areas of the left angular gyrus and bilateral parietal lobes as being defective in dyslexic readers. The left angular gyrus has been thought to be the center for visual memory of words and letters. And the inferior posterior parietal area of the cerebral cortex can serve "as a point of

confluence for visual, auditory, and somesthetic impulses from the association areas concerned with these sensory modalities and hence can serve the role of integrating information from them (Benton, 1975, p. 32)." Benton goes on to state the following:

> The correlation between capacity for intersensory integration and reading skill has been the subject of intensive study in recent years. Through such a mechanism, faulty or retarded development of the posterior parietal region may prove to be the structural basis for specific failure to learn to read (p. 31).

The other theory -- defect in the overall organization of cerebral function -- was first proposed by Orton in 1925. The theory has been altered and gained sophistication since Orton's time largely because more elaborate methods of assessing cerebral function have been developed subsequently. Cerebral functional organization (hemispheric specialization) and reading disability will be dealt with in the next major section of the present review.

Some neurological theorists (e.g. Aaron et al, 1980; Benton, 1978; Mattis, 1978) propose that it may be instructive to compare aquired alexia (usually displayed by adult patients who lost the ability to read as a result of brain damage) with developmental dyslexia (children who fail to acquire reading at the expected rate). There are various types of alexia (Albert, 1979; Benton, 1975; Gaddes, 1975; Geschwind, 1962; Hecaen and Kremin, 1976; Mattis, 1978). A brief review of Albert's article will serve to highlight these types of acquired alexia. Albert (1979) defines alexia as "... an acquired inability to comprehend written language, as a consequence of brain damage (p. 59)." He states that "... for all the words that have been written, virtually all authors agree that there are two principal varieties of alexia: alexia without agraphia versus alexia with agraphia (p. 65)." Albert then describes these two alexic syndromes:

1. Alexia without agraphia -- this syndrome includes impaired comprehension of written language, impaired ability to copy, and acalculia. Oral language is normal or nearly normal and both

writing and spelling are normal. Subtypes of pure alexia are literal alexia (cannot read letters but can read words), verbal alexia (unable to read words but can read and identify letters), alexia for sentences (cannot read sentences and paragraphs but can read letters and words), and global alexia (inability to read letters, words, and sentences but can read digits). According to the disconnection theory, a lesion in the left visual area prevents visual stimuli entering to the left hemisphere from reaching the left angular gyrus which is necessary for reading, while visual stimuli which enter the intact right hemisphere are prevented from reaching the left hemisphere because of the destroyed splenium at the corpus callosum. Most cases of pure alexia result from cerebrovascular lesions.

2. Alexia with agraphia -- There are two types of alexia with agraphia (alexia-agraphia and aphasic alexia). Patients with alexia-agraphia cannot read long words or long sentences (verbal alexia) and disorders of writing are severe. Associated findings are apraxia and acalculia. Alexia-agraphia is associated with lesions of the left angular gyrus. The reading disorder of aphasic alexias may be like the literal alexic (cannot read letters but can read words)or like the verbal alexic (cannot read words but can read letters) depending on the location of the lesion. Writing is always defective. Associated deficits include acalculia and a variety of oral language disturbances. In aphasic alexia the lesion includes the left angular gyrus and extends to involve the posterior temporal region (pp. 66 - 75).

It is interesting to compare developmental dyslexia with acquired alexia but, obviously, more work is required to make such comparisons more tenable.

A final matter for discussion on neurological aspects of reading difficulty is the conceptualization of developmental dyslexia by Jorm (1979). He suggests that developmental dyslexia is a genetically-based dysfunction of the inferior parietal lobule, a region important in both reading and short-term memory. According to Jorm, developmental dyslexics have difficulty in accessing the meaning of written words via phonological recoding. Moreover, this difficulty with phonological recoding is explained, by Jorm, in terms of a short-term memory deficit. Jorm (1979) suggests that studies on visual evoked potentials and studies on the development of the human brain confirm his position. In addition, he states the following:

> A fully adequate theory of the neurological basis of dyslexia should be able to show that: (a) the neurological system hypothesized to be involved in the disorder is crucial to those components of the reading process which are affected in dyslexia, (b) this neurological system is also crucial to the fundamental cognitive process which is deficient in dyslexia, and (c) this neurological system does not function normally in dyslexics. I will show that the theory advanced in this article fulfills all of these criteria (p. 26).

This concludes the discussion on neurological aspects of reading difficulty. The purpose of considering neurological aspects was to argue in favor of including these factors for a thorough description of reading disability. Some work in the neurological area was highlighted. The next and final topic of inclusion for the description is an important one -- developmental aspects of reading difficulty.

Developmental Aspects

For a thorough description of reading difficulty, developmental aspects need to be included as well. A major consideration here is whether or not deficits associated with reading difficulty are different for different age groups. Another concern is whether or not reading difficulty in older children could have been predicted on the basis of some indicator when they were younger. A third issue relevant to developmental aspects of reading difficulty is the transiency or intransiency of the disorder. That is, can reading difficulty best be characterized as developmental delay which is transient and which can be "outgrown" or is reading difficulty an intransient deficit for which total recovery rarely occurs? These topics will now be discussed.

Regarding possible changes in deficits associated with reading difficulty, Torgesen (1975) states the following:

> ... although any conclusions about underlying process deficits must remain tenuous, there is evidence that the tasks which differentiate between normal and retarded readers are different at different ages. ... A clearer understanding of age-related changes in the factors associated with reading problems can best be attained through the use of developmental paradigms in reading-disability research. ... Both longitudinal studies, which chart the development of a single sample of children through time, and cross-sectional designs, which compare the performance of different age groups at one point in time, would contribute significantly to a more comprehensive understanding of deficiencies associated with reading failure (p. 421, 422).

Accordingly, some cross-sectional and longitudinal studies will be presented next. The topics of change, prediction, and transiency will be dealt with in the context of these studies.

Vellutino, Smith, Steger, and Kaman (1975) conducted a cross-sectional study to determine if reading disability can be best explained by a perceptual-deficit hypothesis or by a verbal-deficit hypothesis for children at different age levels. Since Vellutino prefers the verbal deficit hypothesis (Vellutino, 1977, 1978, 1979), he and his associates hypothesized that both

young and older reading disabled children would be poorer than normal readers with respect to verbal encoding but that there would be no difference in visual encoding comparing reading disabled to normal readers at two grade levels. For this study, 84 children (21 poor and 21 normal readers in grade 2 and grade 6) were presented with tachistoscopic exposures of both verbal and nonverbal stimuli and were asked to identify and/or reproduce them both orally and graphically. As predicted by Vellutino et al (1975):

> Poor readers in both second and sixth grade performed as well as normals in the immediate visual recall of geometric designs having no (specific) linguistic referents. They also manifested considerably greater accuracy in copying, and naming letters in words than they did in pronouncing those same words (e.g., loin/lion; was/saw). Moreover, the performance of poor readers on letter reproduction and naming closely approximated that of normal readers but was uniformly inferior to normals in word identification and spelling. Similarly, poor readers differed from normals on the types of errors they made only in the case of oral encoding but not in graphic reproduction (p. 492).

The experimenters suggest that the results provide indirect evidence for the possibility that reading disability occurs because of a verbal mediation disorder at both age levels.

On the other hand, different results were obtained from a cross-sectional study conducted by Sobotka, Black, Hill, and Porter (1977). They compared psychological test performance of 24 dyslexic boys and 24 normal readers using four age levels (7, 9, 11, and 13 years). "All children were administered a psychological battery composed of measures of perceptual and perceptual-motor abilities (WISC Performance I.Q., Bender-Gestalt, and an auditory-visual integration test) and of verbal-cognitive skills (WISC Verbal I.Q., two dichotic listening tasks, and a test of word fluency (Sobotka et al.,abstract, p. 363)." The results of the testing revealed that verbal differences between dyslexic and normal readers were found at all age levels but nonverbal differences between the two reading groups were found only at the youngest age (p. 366). Sobotka et al.(1977) conclude that "...the perceptual-motor deficits found in the younger

dyslexic children on performance tasks decrease over time. Thus, developmental differences supporting the maturational-lag hypothesis were seen on nonverbal tasks only (pp. 366 - 367)."

The two studies reviewed above found similar results regarding verbal differences between reading disabled children and normal readers at both younger and older age levels. However, the studies differ regarding nonverbal tasks. The Vellutino et al.study found no differences between good and poor readers at both age levels while the Sobotka et al.study found significant differences between good and poor readers on nonverbal tasks at age 7, only. As shall be discussed, longitudinal studies have addressed these same issues.

Paul Satz and various associates have written a number of articles about a longitudinal study on reading disability (Fletcher and Satz, 1980; Satz and Friel, 1974; Satz and Friel, 1978; Satz, Friel and Rudegeair, 1974; Satz, Friel and Rudegeair, 1976; Satz, Rardin and Ross, 1971; Satz and Sparrow, 1970; Satz, Taylor, Friel and Fletcher, 1978; Sparrow and Satz, 1970; and Taylor, Satz and Friel, 1979). Satz, Rardin, and Ross (1971) discuss a theoretical formulation of specific developmental dyslexia and propose the following hypothesis (p. 2013):

> Hypothesis 1: Younger dyslexic children will be more delayed in visual-motor integration and auditory-visual integration than younger control children.
>
> Hypothesis 2: Older dyslexic children will not be more delayed in visual-motor integration and auditory-visual integration than older control children.
>
> Hypothesis 3: Older dyslexic children will be more delayed in language integration skills than older control children.
>
> Hypothesis 4: Younger dyslexic children will not be more delayed in language integration skills than younger control children.

Satz, Rardin, and Ross found substantial confirmation for Hypotheses 2 and 3 and partial confirmation for Hypotheses 1 and 4. Such results would justify a close look at their theory.

The theory formulated by Satz and his associates is explained in Satz and Sparrow (1970) and Sparrow and Satz (1970). Excerpts from Satz and Friel (1974) will highlight the theory under scrutiny:

> The Theory postulates that developmental dyslexia is not a unitary syndrome but rather reflects a lag in the maturation of the brain which delays differentially those skills which are in primary ascendancy at different chronological ages. Consequently, those skills which during childhood develop ontogenetically earlier (e.g., visual-perceptual and cross-modal integration) are more likely to be delayed in younger children who are maturationally immature. Conversely, those skills which during childhood have a later or slower rate of development (e.g., language and formal operations) are more likely to be delayed in older children who are maturationally immature. ...
> Briefly, the theory is compatible with those developmental positions which postulate that the child goes through consecutive stages of thought during development, each of which incorporates the processes of the preceding stage into a more complex and hierarchically integrated form of adaption (Piaget 1926, Bruner 1968).
> This evolving developmental process, however, is postulated to be delayed in those children who are maturationally immature. As a consequence, the child lags in those developmental skills which have been shown to be crucial to the early phases of reading -- learning to differentiate graphic symbols (Gibson 1968) or perceptual discrimination of letters (Luria 1966). ...
> Thus, the theory postulates that those developmental skills which are in primary ascendancy during the preschool years are, if delayed, more likely to forecast later problems in reading and writing by grade 1 and 2. This position eschews a disease model (e.g., brain damage) and attempts to explain the reading disorder within the context of a developmental model -- the lag in brain maturation is treated as a hypothetical construct (pp. 437 - 438).

Having highlighted possible hypotheses and the theoretical formulation of Satz and his colleagues, some findings from their longitudinal study will be presented next. In short, their position is that correlates of reading disability change with age, that predictive antecedents of later reading disability would likely be skills related to visual-perception and cross-modal integration, and that reading disability can best be characterized by the maturational-lag hypothesis.

For the study under discussion, 497 white male kindergarten children were first tested in 1970 and 181 of these were retested in 1976 (end of Grade 5). As reported in Fletcher and Satz (1980), tests were used to tap sensorimotor-perceptual skills (Recognition-Discrimination, Beery VMI, Embedded Figures, Finger Localization), verbal-conceptual skills (Similarities, PPVT, Verbal Fluency), and verbal-cultural experience (Auditory-Discrimination and Alphabet Recitation). Comparing 1970 test predictions with 1976 outcomes, the valid positive rate was 86% in the severe reading disabled group, 20% in the mild reading disabled group, 64% in the average reading group, and 86% in the superior reading group (Satz, Taylor, Friel and Fletcher 1978). Hence, predictive accuracy was largely confined to the extremes of the reading distribution.

Regarding the ranking of predictor variables in terms of their criterion discrimination,"... the Finger Localization Test ranked highest, followed cumulatively by the Peabody, Beery, and Alphabet Recitation Tests (Satz et al, 1978, p. 327)." Two of these tests (Finger Localization and the Beery VMI) loaded on sensorimotor-perceptual skills. As stated in Fletcher and Satz (1980), "although perceptual, linguistic, and conceptual skills all seemed related to the developmental process of reading acquisition, the degree of this relationship changed with age in a manner consistent with the developmental hypothesis outlined previously (p. 34)." Finally, the prognosis of reading disability was found to be very poor: there was virtually no improvement in the problem readers between Grades 2 and 5 (Satz et al.,1978, p. 347). In fact, the disabled readers did not "catch up" with normal readers. Similar results on prognosis were found by Trites and Fiedorowicz (1976). They tested 27 reading disabled children at an average age of 11.6 and retested them at age 14.1. Trites and Fiedorowicz state that "results of this study point strongly toward the conclusion that, in subjects with specific reading disabilities, the deficits not only persist with age but tend to grow larger relative to their age and grade placement (p. 47)."

Another longitudinal (follow-up) study on reading disability was

conducted by Rourke and Orr (1977). As stated by Rourke and Orr (1977), the purpose of their study "... was to determine the relative predictive accuracy for reading and spelling performances of a number of measures administered during the first phase of a 4-year longitudinal study of the neuropsychological abilities of normal and retarded readers (p. 10)." They selected 23 normal readers and 19 reading retarded children from a population of Grade 1 and Grade 2 male students. The subjects were initially tested and retested 4 years later on the following: Word knowledge (Metropolitan Achievement Test), Reading subtests (Metropolitan Achievement Test), the Underlining Test (assesses the speed and accuracy of visual discrimination for verbal and nonverbal stimuli), the WISC, the PPVT, and the Reading and Spelling subtests of the Wide Range Achievement Test. The WISC and MAT were used to classify students in the normal reading group or in the reading retarded group. Rourke and Orr summarize their findings as follows:

> In summary, if confirmed by cross-validation, the results of the current investigation would suggest that performance on the Underlining Test is a far more potent means of identifying retarded readers who are "at risk" (at ages 7 - 8) with respect to eventual reading and spelling achievement (at ages 11 - 12) than are the measures of psychometric intelligence, reading or spelling which were used (p. 19).

In addition, they suggest that these results offer some support for the view of Satz and his colleagues that younger retarded readers exhibit poor performance on visual-perceptual and visual-motor tasks as compared to that of age-matched normal readers. Finally, Rourke and Orr found that three-quarters of the reading retarded group made little progress in reading achievement over the 4 years of the study.

A number of conclusions on developmental aspects of reading difficulty can be suggested on the basis of the discussion presented above. First, it does appear that reading disability is developmental in that it is associated with different deficits at various ages. Even though verbal deficits may be associated with reading disability at all age levels,

one might conclude that perceptual difficulties discriminate between normal and poor readers especially at younger age levels. Secondly, prediction of reading disability is most accurate for the extremes and perceptual tests should be included in the prediction battery. Thirdly, the prognosis for reading disability appears to be poor. It would appear that the only abilities of poor readers that "catch-up" are perceptual skills. Thus, according to Rourke (1976):

> ... the developmental lag position is tenable in the case of fairly simple, early-emerging abilities. ... However, until it is shown that retarded readers, either as a group or individually, eventually "catch-up" in those abilities thought to subserve the reading function -- and, for that matter, until it is actually shown that they actually "catch-up" in reading itself -- the weight of the evidence would appear to favor a deficit rather than a developmental lag position (p. 136).

Finally, Dalby (1979) suggests that the delay-deficit distinction may be more academic than real: "it should be evident that the question of deficit or delay is difficult to apply even to an individual. A maturational lag may result in faulty organization, a deficit. In like manner, brain damage in children is rarely static and may result in a delay in development (p. 257)."

This concludes the present section of the review on a description of reading difficulty. To recapitulate, a number of models on reading ability and disability were presented. It was found that the system model better describes reading disability than the assembly model and that more complex models of reading disability require more complex statistics for analysis. Then the verbal-deficit hypothesis was discussed but subsequent information on the variability of reading disability tended to favor a multi-dimensional approach. Accordingly, research on various types or subgroups of reading disability was reviewed. This approach looks very promising. Finally, after considering more general features of reading difficulty, specific aspects -- neurological and developmental -- were dealt with next. The final section of the present review will reconsider the topic of hemispheric specialization in specific reference to reading disability.

HEMISPHERIC SPECIALIZATION AND READING DIFFICULTY

The major purpose of the present section is to review a number of studies on the relationship between hemispheric specialization and reading difficulty. The objective here is to determine if one can propose, on the basis of existing research, that children with reading difficulty are either more or less specialized during cognitive activities than normal readers. Special attention will be directed toward studies that compare an experimental group (poor readers) with a control group (normal readers) using various cognitive, neuropsychological, and psychophysiological methods which are said to tap cerebral asymmetry.

Prior to presenting experimental research, background information on hemispheric specialization and reading disability will be discussed. Specifically, information pertaining to historical hypotheses, assumptions, and views of prominent researchers will introduce the section. A major portion of the present section will then be devoted to a discussion of experimental research on hemispheric specialization and reading difficulty. Next, approaches to remediation of reading problems will be highlighted. Particular attention will be given to remedial approaches which can be based on neurophysiological assessment. Two approaches to remediation seem compatible with the existing research on the neuropsychology of reading difficulty -- EEG biofeedback training and teaching strategies. Finally, the chapter will conclude with a number of hypotheses drawn from the present review of research and literature.

Background Information

According to Harris, four hypotheses on the relationship between lateral dominance and reading disability were developed during the 1930's and 1940's. Harris summarizes each of these views as follows:

> The most widely known view was that of Orton (1939). He assumed that sensory impulses were received by both hemispheres simultaneously, and memory traces were formed that were mirror images of each other. If one hemisphere was clearly dominant, the memory traces in the nondominant hemisphere would be suppressed and normal perception would result. But if dominance were incomplete, control could alternate between the two hemispheres, and the result for reading would be shifting and inconsistent perception with many reversal errors.
>
> A second hypothesis (Dearborn 1933) placed emphasis on motor conflict. Dearborn stated that in writing we tend to pivot at the elbow and find it easier to move outward from the middle of the body than to move across the midline. When the person is not definitely right- or left-sided, competing motor tendencies develop that in turn produce inconsistent eye movements and confused visual perception.
>
> Gesell and Amatruda (1941) argued that when mixed dominance is accompanied by language disability such as defective speech or reading disability, it is because there is a neurological defect or deficiency in the naturally dominant side of the brain. The mixed dominance and disability both result from the neurological deficit. This view is very much alive today.
>
> A forth explanation applied only to the small number whose handedness has been changed from left to right by the use of force, punishment, or ridicule. It was supposed that not the fact of change but the method of doing it produced an emotional blocking that disrupted learning (p. 338).

The above hypotheses suggest that there is a relationship between physical laterality (i.e. handedness, eyedness, footedness), cerebral organization, and reading disability. With the advent of more precise measurements of cerebral organization (e.g., dichotic listening, tachistoscopic presentation, EEG, evoked potential, rCBF) the emphasis on

handedness is diminishing (Corballis and Beale, 1976). Failure to distinguish between physical laterality and cerebral laterality (organization) has led to great confusion in this area of research (Kinsbourne and Hiscock, 1978). Moreover, according to Satz (1976), the relationship between handedness and reading disability obscures the issue. His statement on this problem is as follows:

> The presence of directional confusion, incomplete handedness, and mixed hand-eye preference represents additional symptoms that have been adduced as support for the construct (unobservable) of incomplete cerebral dominance. It is the contention of this paper that the second group of symptoms (especially deviant hand and/or eye preference), while traditionally the basis of evaluation of the theory, are not essential, if even relevant, to the theory (p. 276).

Hence, the emphasis for the present review is on the specific relationship between cerebral organization, not physical laterality, and reading difficulty.

There are four basic assumptions, explicit or implicit, in nearly all studies on cerebral lateralization and learning disability (Kinsbourne and Hiscock, 1978). Kinsbourne and Hiscock elaborate on the following four assumptions:

1. Learning disability can be defined adequately and is unitary or monolithic in nature.

2. One can specify what is meant by cerebral lateralization.

3. The most prevalent pattern of cerebral organization (that is, left lateralization of language) is optimal and deviations from this norm imply some impairment of function.

4. Lateralization develops ontogenetically (p. 196).

After devoting a major portion of their article to a discussion of these assumptions, Kinsbourne and Hiscock suggest that the four basic assumptions are unfounded. Their view is that "...the laterality of language representation probably has no relevance to language performance (p. 221)."

Prior to presenting various experiments on cerebral asymmetry or hemispheric specialization and reading disability, the views of two other researchers -- Satz and Naylor -- will be considered. Satz (1976) revisits the old problem of cerebral dominance and reading disability by first discussing Orton's theory and then reviewing both dichotic listening studies and visual half-field studies (tachistoscopic presentation). His conclusion is not promising:

> One might ask what light the preceding review of laterality studies sheds, if any, on the problem of cerebral dominance and reading disability. The answer should be -- not much. The reason for this somewhat discouraging view lies in the numerous methodological and conceptual problems that continue to plague research efforts in this area. With the advent of binaural rivalry procedures in audition and tachistoscopic procedures in vision during the 1960's, it was hoped that more direct assessment of functional hemispheric mechanisms in normal and disabled readers would result. Unfortunately, the preceding review indicates that answers to this question - and the one posed by Samuel Orton four decades ago - will not be available until further progress is made in both methodology and theory (p. 288).

Naylor (1980) does not appear to be any more optimistic regarding cerebral laterality and reading disability. His conclusion is similar to Satz's:

> This review of laterality studies with reading-disabled children indicates that there is little evidence either that these children are more bilateral than normally reading children in cerebral organization or that they have a specific deficit in left-hemisphere processing (p. 542).

Notwithstanding the above views, it would seem worthwhile to discuss experimental findings from research on cerebral organization and reading difficulty. Furthermore, results from psychometrics, EEG, and evoked potential studies will be presented in addition to results from dichotic dichhaptic, and tachistoscopic studies. At the outset, it is important to realize that the studies to be reviewed are not without limitations (see Satz, 1976 and Naylor, 1980 for detailed explanations).

Functional Asymmetry and Reading Difficulty

The topic of functional asymmetry of normal right-handed subjects was considered in the first section of the present review. A major conclusion drawn from experimental evidence was that hemispheric specialization seemed to be a viable construct with respect to normal right-handed subjects. In general, the left hemisphere of the subjects was found to be more involved in processing linguistic information than the right hemisphere and the right hemisphere was found to be more involved in processing non-linguistic information as compared to the left. The model proposed was not an "all or none" model but rather one which emphasized a "more or less" relationship. Regarding the development of hemispheric specialization, conclusive statements were not posited but perhaps an answer may be discovered with better controlled studies.

Information presented in the second section of the present review suggested that certain subskills related to reading follow a developmental course;sensorimotor perceptual skills develop or mature prior to verbal-conceptual skills. Moreover, some researchers suggest that such a developmental sequence is slower in reading disabled children than in normal readers. In addition, it was suggested that the poor prognosis of children with reading difficulty would tend to cast doubt on the developmental lag hypothesis. The next task then is to relate hemispheric specialization to reading difficulty by examining studies on cerebral functional organization of poor readers.

Psychometric Assessment and Reading Difficulty

Three psychometric studies will be highlighted. The purpose of the first study (Guyer and Friedman; 1975) was to test cognitive skills and cognitive style in 41 learning disabled and 41 normal children, aged 7.7 to 12.7 years old. The cognitive test battery included the following: portable rod-and-frame test, hand awareness test, degree of lateralization, the equivalence test (a measure of verbal conceptual development),

various left hemisphere tests (auditory sequential memory -- ITPA, verbal recognition, verbal closure), and various right hemisphere tests (visual sequential memory -- ITPA, visual recognition, and visual closure). One note of caution is appropriate prior to the discussion of results. That is, there is probably no <u>pure</u> measure of left or right hemispheric function. Although both hemispheres are probably active during any cognitive challenge, one hemisphere may be <u>more</u> active than the other depending on the nature of the task. Guyer and Friedman (1975) state a number of results from their study:

> The major findings of this study can be summarized as follows: (1) No support was found for the hypothesis that learning disability is related to incomplete or crossed hand and eye dominance. (2) Confirmation was found for the relationship between body awareness and field independence reported by Witkin (1962). (3) On most tests of cognitive processing, learning-disabled children were found to perform as well as normal control children when age and I.Q. were controlled. (4) The cognitive processing abilities that were deficient in learning-disabled children can all be theoretically related to left - or dominant-hemisphere functioning. (5) Language development does not appear to be a unitary factor (pp. 665 - 666).

An interesting, if not plausible, suggestion by Guyer and Friedman is that learning-disabled children may be attempting to use a nonverbal (right hemispheric) information processing mode to deal with academic tasks. A similar hypothesis has been proposed by Witelson (1977b) which will be discussed later.

A second study using cognitive tests as the dependent variable was conducted by Rourke and Finlayson (1978). Forty-five 9 to 14 year old children with learning disabilities were divided into three groups on the basis of reading, spelling, and arithmetic achievement:

<u>Group 1</u>: children were deficient in reading, spelling, and arithmetic,

<u>Group 2</u>: children were deficient in reading and spelling but not in arithmetic,

<u>Group 3</u>: children were not deficient in reading and spelling but were deficient in arithmetic.

The 16 cognitive tests used as dependent measures can be divided into two main categories -- verbal perceptual, auditory perceptual and visual perceptual, visual spatial -- according to Rourke and Finlayson (pp. 125 - 126). They found that "the performances of Groups 1 and 2 were superior to that of Group 3 on measures of visual perceptual and visual spatial abilities; Group 3 performed at a superior level to that of Groups 1 and 2 on measures of verbal and auditory perceptual abilities (abstract, p. 121)." One conclusion reached on the basis of the Rourke and Finlayson study was that subjects in Group 3 (relative deficiencies in arithmetic) performed as would be expected were they to have a dysfunctional right hemisphere and subjects in Group 1 and 2 (relative deficiencies in reading and spelling) performed as would be expected were they to have a dysfunctional left hemisphere. Speculating here, perhaps Groups 1 and 2 are not cerebrally specialized to process verbal information and Group 3 may not be specialized to process visual perceptual or spatial information. At any rate, findings from Rourke and Finlayson's study provide empirical support and a possible method for subgrouping different types of children with learning disability. The next study also provides evidence for subgrouping children having difficulty in learning to read.

Dalby and Gibson (1981) investigated functional cerebral lateralization in subgroups (Boder's classification) of reading-disabled boys (9 - 12 years old). Once grouped (dysphonetic, dyseidetic, and normal reading-spelling errors), experimental and control subjects were then tested on three experimental neuropsychological measures (hemispheric time-sharing, conjugate lateral eye movements, and tactile directional perception). According to Dalby and Gibson, results from hemispheric time-sharing and tactile lateral perception measures demonstrated atypical lateralization in the reading-disabled groups. Specifically, the non-specific disabled readers (normal reading-spelling errors) displayed a group pattern of left lateralization of verbal functions and bilateral representation of spatial functions, the dysphonetic was

characterized by bilateral organization of both verbal and spatial functions, and the dyseidetic group displayed bilateral verbal representation and right lateralization of spatial functions. According to Dalby and Gibson, it is possible that the absence of hemispheric specialization in both the dysphonetic and dyseidetic groups may be related to their respective dysfunctions. For the hemispheric time-sharing task, normal control subjects displayed left lateralization of language and right lateralization of spatial functions. The findings presented here are in accordance with the hemispheric specialization hypothesis (normal readers are more specialized than poor readers). This hypothesis will be examined by reviewing findings from studies which use more direct measures of cerebral organization (dichotic, tachistoscopic, EEG, and evoked potential).

Dichotic Listening Studies and Reading Difficulty

Using the dichotic listening technique, both Zurif and Carson (1970) and Thomson (1976) found that the dyslexic group showed a less well established dominance of hemispheric function than the normal control group. As part of their experiment, Zurif and Carson presented dichotic digits to 14 poor and 14 normal readers in Grade 4. In contrast to the normal readers who showed a right ear superiority, the dyslexics tended to be better in reporting material delivered to the left ear. In other words, normal readers tended to use their left hemisphere more than their right hemisphere during the dichotic digits task while the dyslexics did not. The experimental procedure used by Thomson was dichotic presentation of digits, words, reversible words (saw/was), similar words (big/pig), and reversible nonsense syllables (mag/gam) to 20 poor and 20 normal readers aged 9 - 12 years old. Thomson (1976) found that "the control group showed the right ear superiority effect for digits, words, reversible and similar words. The dyslexic group showed no difference or a left ear superiority for these tests, and a right ear effect for the nonsense syllables (abstract, p. 243)." The lack of cerebral specialization inferred from performance on dichotic listening tasks may be related to reading disability. Both

of the above studies did not separate subjects into different age groups which is, as has been argued previously, important in research on reading disability.

The next studies are developmental experiments on dichotic listening and reading difficulty. Bakker (1973) presents and discusses a number of dichotic listening experiments on normal and poor readers. In general, Bakker and his associates found that each stage in the learning-to-read process is characterized by an optimal lateralization pattern: early reading (age 7) requires no dominance, in between stages (age 9) require a moderate degree of dominance, and fluent reading (age 11 and above) requires maximum dominance (p. 25). In addition, Bakker found that poor readers (age 9 - 13) were similar to normal readers two years younger with respect to dominance of function or hemispheric specialization. Referring to these studies in a later publication (Bakker 1979a), Bakker points out that inferences regarding the relation between side of lateral preference and reading proficiency were not made since ear asymmetry was analyzed in terms of absolute between-ear differences (p. 140). However in subsequent experiments Bakker and his associates considered left and right ear advantage. They found that early reading is less dependent on left hemispheric functioning than advanced reading (Bakker, 1979a). As stated by Bakker:

> Left and right representations of language are associated with different reading strategies, especially at younger school ages. Initial reading is psycholinguistically one thing; advanced reading another. This distinction seems to parallel a neuropsychological one: a left hemispheric representation of language subserves advanced reading; a right hemispheric representation subserves initial reading. Thus functional maturity of the right hemisphere may be of importance to the early stages of the learning-to-read process (p. 143).

Finally, Bakker's view on dyslexia is presented at the conclusion of yet another publication (Bakker 1979b). Bakker (1979b) suggests that there are two dyslexias (p. 98): "reading problems may originate either from a premature application of syntactic-semantic strategies, usually generated by the left hemisphere (type I dyslexia), or an excessive and persisting

application of spatio-perceptual strategies, usually released by the right hemisphere (type II dyslexia)." Bakker's analysis is important for three reasons: 1) it suggests that the right-ear advantage (REA) for dichotically presented verbal information may not be beneficial for all stages of reading, 2) it fits well with the developmental sequence of the learning to read process and with other developmental theories of reading disability (eg. Satz), and 3) it may provide a rationale for subgrouping types of reading disability on the basis of cerebral organization.

On the other hand, a study by Obrzut, Hynd, Obrzut, and Leitgeb (1980) lends support to the notion that cerebral lateralization is not a developmental phenomena. The experimenters used time-sharing and dichotic listening techniques to examine cerebral lateralization for language function in 48 normal and 48 learning-disabled children. Subjects were divided into three age levels (7-0 to 8-5, 8-6 to 10-4, and 10-5 to 11-11 years). Obrzut et al. found that both the normal and learning-disabled groups demonstrated left lateralization of language and no developmental trends were evident (p. 189). The conclusion reached from this study is that a lack of hemispheric specialization may not be related to learning disability.

A final study on dichotic listening was conducted by Newell and Rugel (1981). They dichotically presented digits and melodies to 32 right-handed male disabled readers and 32 right-handed male normal readers. Subjects were divided into young (9 to 10 years old) and old (11 to 12 years old) groups. Newell and Rugel summarize their results as follows:

> On the dichotic digits test, both normals and disabled readers showed the right ear left hemisphere superiority typically found with linguistic information. In addition, the deficit of disabled readers relative to normals was with the left ear thus suggesting a right cerebral hemisphere deficit. Additional evidence for a right cerebral hemisphere deficit is present in the melodies test. On this task a left ear right cerebral hemisphere superiority was found with the normals as is typically the case with musical information. However, disabled readers showed a right ear superiority suggesting dominant use of the left hemisphere in processing musical information normally processed by the right cerebral hemisphere. This also is consistent with the notion of a right hemisphere deficit in disabled readers (p. 297).

The controversy continues. Bakker and Obrzut et al. come to different conclusions regarding development and reading difficulty. Moreover, results from the study by Newell and Rugel were not in accordance with those found by Zurif and Carson and by Thomson. The resolution of the issue may require carefully controlled studies which use a combination of experimental techniques (dichotic, tachistoscopic, EEG, and evoked potential), divide disabled readers into subgroups, and divide subjects into different age levels. The next topic for discussion is experimental research on reading disability and hemispheric specialization using the tachistoscopic technique.

Tachistoscopic Studies and Reading Difficulty

Studies which use the tachistoscopic technique to investigate hemispheric specialization and reading difficulty have found conflicting results, as well. Some studies have found that normal and poor readers are not different with respect to cerebral asymmetry (McKeever and Huling, 1970; McKeever and Van Deventer, 1975; Yeni-Komshian, Isenberg, and Goldberg, 1975). Other studies have found that poor readers are less specialized than good readers in processing verbal information (Marcel, Katz and Smith, 1974; Marcel and Rajan, 1975; Kershner, 1977). Finally, findings from a cross-sectional developmental study (Olson, 1973) suggest that younger disabled readers are less specialized than younger normal readers but that older disabled readers are just as cerebrally specialized in comparison to older normal controls. A brief presentation of findings from each of these studies will serve to confirm the controversy. Recall that a strong right visual field advantage (RVF-Ad.) for linguistic-sequential information is the expected specialized pattern and a strong left visual field advantage (LVF-Ad.) for spatial-holistic information processing is expected.

Pertinent findings from the studies mentioned above regarding tachistoscopic presentation of information to poor and normal readers are as follows:

1. McKeever and Huling (1970) -- Words directed to the left cerebral hemisphere (right field words) were recognized significantly

more often ($P<0.005$) in both groups (grade 7) than words channelled to the right hemisphere (p. 600).

2. McKeever and Van Deventer (1975) -- ...findings are compatible only with the conclusion that the dyslexics, (age 12.9 to 13.9 years) like the controls (age 12.7 to 13.7) are characterized by left hemisphere language specialization (p. 374).

3. Yeni-Komshian, Isenberg, Goldberg (1975) -- The findings concerning the laterality differences between the two groups [good (age 11.8) and poor (age 12.8) readers] seem to contradict the hypothesis that disabled readers are not as well lateralized as normal readers (p. 91).

4. Marcel, Katz, Smith (1974) -- Five-letter words were presented unilaterally to left or right of a fixation point. Subjects were 7.6 to 8.7 years old. Good readers showed greater right over left field superiority than poor readers (p. 131).

5. Marcel and Rajan (1975) -- Five-letter words were presented in one session and unfamiliar faces in a second session a week later. Subjects were 7 - 9 years old. In the first task good readers showed greater right field superiority than poor readers. In the second task, a left visual field superiority was demonstrated for faces, but the extent of this asymmetry was not related to reading ability nor to the extent of lateral asymmetry in word recognition (p. 489).

6. Kershner (1977) -- The results show that children with reading disability (age 10) compared with fluent readers (age 10), when tested tachistoscopically under bilateral conditions have a lower right-over left-field advantage in word perception (p. 65).

7. Olson (1973) -- Children aged 7 - 11, with normal reading ability showed a right visual field preference for word recognition whether words were presented to each field singly or simultaneously. A heterogeneous group of delayed readers showed similar findings including an enhanced right field preference for bilateral field presentations. A young group of delayed readers (aged 8 - 9) without known physical, intellectual, emotional or cultural deficits failed to show any field superiority, suggesting an effect of delayed cerebral maturation (p. 343).

Older children were selected for the studies which failed to find differences between good and poor readers in terms of hemisphere specialization (McKeever and Huling, 1970; McKeever and Van Deventer, 1975; Yeni-Komshian et al, 1975). And three of the studies which suggest that good

and poor readers differ in terms of hemispheric specialization (Kershner, 1977; Marcel et al, 1974; Marcel and Rajan, 1975) used younger subjects. Hence, the age of participants may account for the conflicting findings.

One final study on perceptual asymmetry and reading difficulty was conducted by Witelson (1977b). Unfortunately, Witelson did not separate the subjects into different age groups and as a result, the finding from her study cannot be related to her moderate view of the development of hemispheric specialization. However, Witelson's study is noteworthy here because she used a combination of perceptual information processing techniques -- dichotic listening, tachistoscopic presentation and dichhaptic tests. Also, it clarifies one view of developmental dyslexia (two right hemispheres and none left) that is related to hemispheric specialization. For the study, a group of 85 right-handed dyslexic boys (age 6 - 14) were compared with a group of 156 normal right-handed boys (average age of 10.5 years). Four perceptual tests were performed by the subjects:

1. Dichhaptic Shapes Test -- spatial perception of competing nonsense shapes through touch.
2. Tachistoscopic Test -- bilateral presentation of unfamiliar figures of people.
3. Dichotic Listening Test -- simultaneous presentation of digit pairs.
4. Dichhaptic Letter Test -- perception of competing letters through touch.

The first two tests were used to tap spatial processing (right hemisphere), the third test was used to tap verbal processing (left hemisphere), and the fourth test was used to tap both spatial (shape recognition) and verbal (linguistic encoding) processing. The tests and rationale for using them is presented in Witelson (1976). For the dichhaptic shapes test and the tachistoscopic (unfamiliar faces) test, the normal group displayed the characteristic left hand/visual field advantage but the poor reading

group did not. Both groups showed a right ear advantage for the dichotic digits test. Witelson (1977b, p.310) reports that "on the dichhaptic letters test, the normal group showed only a tendency toward naming more right than left-hand letters (...p=.10), whereas the dyslexic group named significantly more left than right-hand letters (...p<.02)." Witelson (1977b) states conclusions from this study as follows:

> Developmental dyslexia may be associated with (i) bi-hemisphere representation of spatial functions, in contrast to the right-hemisphere specialization observed in normal children, and (ii) typical left-hemisphere representation of linguistic functions, as is observed in normal children. The bilateral neural involvement in spatial processing may interfere with the left hemisphere's processing of its own specialized functions and result in deficient linguistic, sequential cognitive processing and overuse of the spatial, holistic mode (abstract, p. 309).

The use of a right hemispheric strategy to process linguistic information may be dysfunctional for reading. Grass and Ruthenberg (1979) challenged Witelson's interpretations. According to them, it would be more beneficial to subgroup poor readers on the basis of age and type of deficiency and then conduct a study similar to Witelson's. Again, this is probably true regarding many of the perceptual studies reviewed above. Various electrophysiological studies on reading difficulty will be presented next.

EEG Studies and Reading Difficulty

In general, research on the relationship between EEG and reading difficulty has not unequivocally shown that a specific association exists (Benton, 1975). According to Hughes (1978), "the presence of questionable and controversial EEG findings is a reflection of the need for further research in a field that otherwise makes a strong contribution in today's clinical setting (p. 207)." Realizing that there are certain limitations involved with conducting electrophysiological research on reading disability, Hughes (1978) reviews a number of these studies. His conclusions regarding the types of EEG abnormality found in dyslexic subjects are (p. 216):

1. Although a definite conclusion cannot be made, in general, positive spikes seem to be more frequently mentioned in studies on dyslexia than other waveforms.

2. The incidence of positive spikes ranges from 20 to 50 percent of dyslexic children tested.

3. Excessive occipital slowing is another waveform commonly mentioned.

4. The data on posterior slowing suggest at least a 10% incidence in learning disabilities or dyslexia, but further studies are clearly needed.

5. A diffuse abnormality or epileptiform activity may be emphasized in some studies but may not even be mentioned in others.

Four studies which have investigated the general EEG pattern of children with reading/learning problems are Gerson et al, 1972; Hughes, 1968; Muehl and Forell, 1973-74; and Sheer, 1976. Findings were similar to those studies reviewed by Hughes (1978).

Three additional studies (Fuller, 1977; Hanley and Sklar, 1976; and Rebert et al.,1978) specifically investigated the electrophysiological involvement of the two cerebral hemispheres during various cognitive activities. Hanley and Sklar (1976) investigated the EEGs of 12 dyslexics (age 9 - 18 years) and 13 normal controls (age 7 - 16 years). The three groups of Boder's (1971) classification -- dysphonetic, dyseidetic, alexic -- were represented in the dyslexic sample. Bipolar electrodes were placed on the following locations of each hemisphere (electrode montage): fronto-temporal (F3-T3 and F4-T4), fronto-parietal (F3-P3 and F4-P4), parieto-occipital (P3-O1 and P4-O2), and occipito-temporal (O1-T3 and O2-T4). The EEG was monitored during seven test phases: rest (eyes closed), attentive (eyes open), mental arithmetic, reading word lists, reading text, auditory perception, and visual perception. Findings from Hanley and Sklar's study are as follows:

1. The most discriminating feature between dyslexic and normal children was the autospectral intensity pattern from the left parieto-occipital derivation. Dyslexic children had greater

energy in the 3 - 7 Hz band and in the 16 - 32 Hz band while normal children had more energy in the 9 - 12 Hz band.

2. During reading, the best discriminating feature was coherence between O2-T4 and T4-F4 in the 16 - 22 Hz band.

3. Within hemisphere coherences were higher for dyslexics while between hemisphere coherences were higher for normal children. That is, normal children showed greater sharing between hemispheres and dyslexic children showed greater within hemisphere sharing.

4. The most recurring difference between dyslexic and normal children was the higher activity in the 3 - 7 Hz band for dyslexics.

According to Hanley and Sklar, "there are several findings in this investigation which seem worthy of speculative comment, with emphasis on the word speculative since there is no claim here to have unravelled the neuropsycholocical substrate of developmental reading dyslexia (p. 234)."

The next study to be reported here was conducted by Fuller (1977). The purpose of his study was "... to determine whether or not LD children show less alpha attenuation when engaged in mental arithmetic and immediate memory tasks compared to a matched group of normal control boys (p. 149)." Recall that there is an inverse relationship between the amount of alpha measured and cerebral activation. That is, as a hemisphere becomes more activated the amount of alpha power present decreases (attenuation). Fuller selected 10 boys with learning disabilities (10.1 - 12.6 years old) and 11 normal control boys (10.6 - 11.7 years old) to participate in his study. Electrodes were placed on parietal (P3, P4) and occipital (O1, O2) regions of the left and right hemispheres. Fuller found that "eight of the 10 experimental LD boys failed to show alpha attenuation in one or more of the three conditions, while 9 of the 11 normal control boys showed alpha attenuation under all three conditions (p. 151)." Since alpha attenuation has been shown to be a concomitant of attention and mental effort, results might suggest that LD children are deficient in attention. According to Fuller, possible causes may be: (1) a specific neurological dysfunction, (2) slow CNS maturation, (3) psychological, and (4) combinations of the above (p. 154).

Regarding EEG frequency analysis of reading disabled children, one other study (Rebert, Wexler, and Sproul, 1978) will be presented. Rebert et al.recorded EEG's from both hemispheres (temporal location) of 11 dyslexic and 11 dysphasic (severe oral language handicaps) subjects (11 - 17 years old). Five experimental conditions used in the study were: eyes closed (relaxed), eyes open (relaxed), reading by subject, reading to the subject, draw a person. Rebert et al. state the following concerning results found from their experiment (p. 441):

> These results indicate that in some children with severe academic difficulties, certain EEG reaction patterns involving hemispheric asymmetry are like those expected in normal adult Ss (eg. the parietal change from reading by subject to draw a person) and more compatible with notions about hemispheric specialization. In other respects, especially in our 'dyslexic' children, the EEG asymmetry patterns appear to be abnormal, and distinguish the 'dyslexic' from another diagnostic group showing somewhat more normal patterns of asymmetry. It may be of significance that the excess left hemisphere theta in the 'dyslexic' group was greater over the angular gyrus than over the temporal region, given suggestions that the left angular gyrus is involved in reading (Geschwind 1972).

The experimenters suggest that their findings are compatible with Witelson's (1977) analysis ("two right hemispheres and none left"). Findings from evoked potential studies will be discussed next.

Evoked Potential Studies and Reading Difficulty

Various studies attempt to differentiate good and poor readers on the basis of each group's measured evoked potentials. After reviewing some of these studies, Hughes (1978) concludes that "... the late components of evoked potentials seem related to both the informational content of the stimulus and the attentiveness of the subjects, and these components tend to be reduced in amplitude when learning disorders are present (p. 234)." In addition, Evans (1977) suggests that evoked potential procedures may be a very useful procedure in objectively investigating attentional disorders of learning-disabled children. Evans concludes that "EP measures appear to be an area with major possibilities for both theoretical and practical

advances in the learning disabilities field (p. 106)." A summary of findings from studies which have used the evoked potential procedure will serve to highlight some of the differences found between normal and reading disabled children.

Results from a number of studies on evoked potentials and reading difficulty are as follows:

1. Conners (1971) -- a family of poor readers is shown to have attenuation of the visual evoked response (VER) in the left parietal area. Studies of two samples of poor readers, and a sample of children with contrasting verbal-performance discrepancies on the Wechsler Intelligence Scale also show significant relationships between verbal skills and the late components of the VER. The strongest VER amplitude correlations occur in the left parietal area (abstract, P. 418).

2. Shields (1973) -- The AER [averaged evoked responses] of brain functioning are clearly different in children with learning disabilities. Most striking are the findings concerning the latencies of the AER wave components. In every case the latency was significantly longer in the learning disabled group than in the normal group (p. 504).

3. Preston, Guthrie, and Childs (1974) -- The reading disabled children showed a significantly smaller amplitude in the negative wave at 180 msec following stimulus onset, for an electrode placed in the region of the left angular gyrus... (abstract, p. 452).

4. Preston, Guthrie, Kirsch, Gertman, and Childs (1977) -- A larger difference was found between words and flashes on the left parietal electrode for normals compared to disabled on the P 200 and LPC [late positive component] measures (abstract, P. 8).

5. Symann-Louett, Gascon, Matsumiya, and Lombroso (1977) -- The present investigation indicates that the maximum visual evoked response wave form differences between the disabled and normal readers are present in the early components recorded over the left superior and inferior parietal areas; i.e., normal readers exhibit more waves than disabled readers (p. 157).

6. Weber and Omenn (1977) -- Amplitudes of auditory and visual evoked responses from right and left hemispheres were compared in subjects from three families having more than one person with reading problems.... There were no differences between dyslexic and normal members of the same family. Investigation

> of dyslexic children from 18 additional families also demonstrated no systematic alteration of the evoked responses over the left hemisphere (abstract, p. 153).

With the exception of Weber and Omenn's study, differences were found in comparing dyslexic to normal readers, especially in the parietal area of the left hemisphere.

Two additional studies on the relationship between evoked potentials and reading difficulty merit discussion. Sobotka and May (1977) compared the visual evoked responses and reaction time performance of 24 dyslexic boys and 24 controls at four different age levels (7, 9, 11, and 13 years). An overall hemispheric asymmetry in VER amplitude (right>left) was observed in both experimental and control subjects. Dyslexics exhibited an <u>increased</u> amplitude to unattended stimuli and a slower reaction time to attended stimuli. These findings are similar to those found by Shields (1973). Also, no significant age by group interaction was found. On the basis of their findings, Sobotka and May suggest that hemispheric asymmetry may <u>not</u> be a good indication of dyslexia, that dyslexia may not result from a maturational lag in neurological development, and that the data are consistent with an "attentional deficit" explanation of dyslexia.

Finally, a recent study on event-related potentials (ERP) of dyslexics was conducted by Fried, Tanguay, Boder, Doubleday, and Greensite (1981). For this study, dyslexics (age 8 - 12) were classified into Boder's (1971) subgroups (5 dysphonetic , 6 dyseidetic, and 2 alexic subjects). Thirteen age-matched normal readers (average age of 10.5 years) were selected as the control group. The stimuli presented were two voiced words (do, go) and two strummed musical chords (A7, D7). Electrodes were placed on the left and right frontal and temporoparietal sites. In discussing their results, Fried et al (1981) state:

> Our finding of greater waveform differences over the left, as compared to the right hemisphere in normal children is consistent with the results of studies which have been carried out in adults. ... The lack of greater word-musical chord ERP waveform differences over

> the left hemisphere in the dysphonetic group suggests that the left hemisphere of the dysphonetic dyslexics may not have a fully developed capacity to process auditory information in a normal manner. ... In contrast to the dysphonetic subjects, the dyseidetic children, who all possessed the capacity to phonemically decode and encode reading materials fairly well, were found to exhibit a normal pattern of left-greater-than-right waveform difference in the present experiment. While they did differ from normal readers with respect to the magnitude of latency and amplitude differences between word and musical-chord ERP's, these results may be attributable to differences in attentional factors between groups (p. 20).

The Fried et al. study confirms the need to subgroup reading disabled children in conducting experimental research.

Findings from evoked potential studies on reading difficulty are not unequivocal but they are promising. In general, it appears that there are both amplitude and latency differences between good and poor readers. These differences may be more prevalent on the left hemisphere than the right, especially for one type of reading disability. The one developmental study reviewed did not show a significant age trend. However , more research is required in this area in order to make conclusions and draw inferences. The final topic for disucssion in this section is approaches to remediation of reading problems.

Approaches to Remediation

Speculative approaches to remediation of reading problems are included here even though the focus of the review of literature and research has been exclusively on assessment. To be sure, the goal of diagnosis is treatment. In addition, the reason for presenting the forthcoming approaches to remediation is simply to show that treatment can be successfully linked to neurophysiological assessment. Finally, it is probably to early to prescribe these approaches for use in reading clinics. The two approaches to remediation presented here are EEG biofeedback training and teaching strategies.

Can human subjects learn to control the activity of their brains? A number of reviews of the research on learned control of brain wave activity seem to converge on one major conclusion -- even if one can learn to control the activity of the brain, the results of such control have not been clearly shown to be of use for treatment (Beatty, 1977; Johnson, 1976; Kuhlman & Kaplan, 1979; and Orne and Wilson, 1978). Some studies have attempted to teach learning disabled subjects to control brain activity using biofeedback (Cunningham and Murphy, 1981; Gracenin & Cook, 1977; O'Malley & Conners, 1972). The only study which reported that EEG training had a positive effect on academic achievement was that conducted by Cunningham and Murphy (1981). They suggest that "training the right hemisphere toward higher arousal and the left hemisphere toward lower arousal resulted in a notable improvement in arithmetic (abstract, p. 204)." One might speculate on possible treatment patterns using EEG biofeedback as a remedy. For example, if it was found that the left hemisphere was overstimulated then one would use visual and auditory feedback to increase alpha amplitude on the left hemisphere. Similarly if it was found that the left hemisphere was under aroused, then the subject would be trained to decrease alpha amplitude on the left hemisphere. Or one could train poor readers at an early age to balance alpha amplitude between the two hemispheres during reading and to increase alpha amplitude on the left hemisphere while simultaneously decreasing alpha amplitude on the right during spatial tasks. Finally, for the

poor reader at an older age level, one could train subjects to decrease alpha amplitude on the left hemisphere and increase on the right during reading. These patterns are highly speculative and have no empirical basis for practice at this time. In sum, EEG biofeedback training as a remedial approach for reading problems awaits further research.

What can be done in the classroom regarding instructional treatment of reading problems? What can the teacher do? Two prescriptions seem to be consistently made regarding the use of knowledge about cerebral function in training children with reading problems (Bogen, 1977; Chall & Mirsky, 1978; Haglund, 1981; Schwartz, 1980; Wittrock, 1978). First, these researchers suggest that right hemispheric activities are not stressed enough in the classroom and, thus, nonverbal activities (e.g. music, art, construction) should receive more consideration by elementary school teachers. Secondly, analytic-sequential strategies should be balanced and integrated with holistic-simultaneous strategies in teaching students a particular lesson. On the basis of neurophysiological research, the following strategies have been suggested as being useful for teaching LD children:

1. If the left hemisphere is weak, teach with visual materials and if the right hemisphere is weak, use verbal materials (Frostig & Maslow, 1979).

2. Send verbal material to the left hemisphere and music to the right using stereo earphones and two tape recorders. Teach to the left hemisphere -- match a visual and auditory symbol, recognize a visual sequence, recognize an auditory sequence, match the two, and pronounce the match in the form of a word (Van den Honert, 1977).

3. Feedback oral reading to the right ear only with the use of a microphone and a headset (Gillis and Sidlauskas, 1978).

Again, the above procedures or strategies seem interesting and they appear to be based on neurophysiological knowledge but further research is necessary.

Some final points can be made regarding remedial approaches for reading disability. The view taken here is that it may be possible to assess neurophysiological weaknesses using the EEG and perhaps other measures of brain function. If this is possible then it would be important to base remedy on what is known about brain function and dys-function. Advances in computer and medical technology can aid the educator greatly. In sum, the remedial approaches suggested above seem to merit consideration but more work needs to be done in this exciting area of research. Perhaps it is best to consider these approaches cautiously and with a healthy skepticism.

In conclusion, the objective of this section of the present review was to determine if, on the basis of the evidence, children with reading difficulty are less specialized (cerebral functional asymmetry) than normal readers. Studies which used psychometrics, perceptual asymmetry measures, and electrophysiological recordings to compare poor with normal readers were reviewed. The findings from these studies are not unequiv-ocal. However, there does seem to be enough evidence to warrant further investigation. Hypotheses on the relationship between reading difficulty and cerebral specialization will be proposed following a summary of the research presented in the present review.

SUMMARY

The review of literature and research was organized in a manner such that general information pertaining to cerebral specialization (asymmetry) and to reading difficulty was presented prior to discussing specific information regarding cerebral specialization of poor readers. Now pertinent information from the previous three sections of the review can be synthesized. The major objective here is to integrate findings from existing research in order to formulate hypotheses on the relationship between cerebral asymmetry and reading performance.

A number of general conclusions may be proposed on the basis of the preceding review. First, the human cerebral cortex would appear to be both structurally and functionally specialized to process higher cognitive tasks. In normal right-handed adults, the left hemisphere appears to exceed during linguistic-sequential cognitive activities and the right hemisphere seems to exceed in processing nonverbal - and spatial - holistic information. Secondly, the onset of cerebral asymmetry or hemispheric specialization has been shown to exist as early as age 3 - 6 months. However, some researchers suggest that cerebral asymmetry is not complete at birth but rather it may develop as a secondary manifestation of cognitive development. Thirdly, reading difficulty is variable and, thus, it may differ according to age level and/or type of deficit. Fourthly, neurological aspects of reading difficulty are important and, as a result, should be considered in order to completely describe the disability. Fifthly, early identification of reading disability is largely confined to the extremes of the continuum and predictive test batteries should include perceptual measures. Sixthly, the prognosis for severe reading disability is poor. Seventhly, a more fruitful approach regarding lateral asymmetry of reading disability is to consider <u>cerebral</u> asymmetry rather than <u>physical</u> asymmetry. Eighthly, regarding cerebral asymmetry of problem readers, it is best to be cautious since there are many conflicting findings in the research literature. However, it would appear that one hypothesis which merits further investigation is that which proposes bilateral

representation of spatial functions. And ninthly, electrophysiological investigations of reading disability may prove useful in delineating subgroups of disabled readers and in determining patterns of cerebral asymmetry of both good and poor readers. This is especially true when electrophysiological recording occurs during cognitive challenges of higher mentation.

Finally, directions for conducting electrophysiological research on reading difficulty can also be derived from the preceding review. Subjects selected for participation should be at the early reading stage (age 7 - 8) and at the fluent reading stage (age 10 - 12). Of course, it would be beneficial to include additional age levels. Electrode placement (montage) would optimally include all sites of the international 10 - 20 system (Jasper, 1959) but, at least, two sites are mandatory -- Wernicke's area (temporal lobe) and the left angular gyrus (parietal lobe) with corresponding placements on the right hemisphere. Both verbal and nonverbal tasks should be performed during EEG recording. And recording from the full frequency spectrum would be optimal but the alpha band (8 - 13) seems most promising. Specifically, alpha power has been shown to be inversely related to cerebral activation. In conclusion, the theoretical frame of reference most clearly reflected in the hypotheses to follow is that developed by Satz and his associates.

HYPOTHESES TO BE TESTED

1. Poor readers at the Grade 3 level will not display cerebral asymmetry during both verbal and spatial tasks.

   a) There will be no difference between EEG alpha band power recorded from the left cerebral hemisphere during reading and drawing.

   b) There will be no difference between EEG alpha band power recorded from the right cerebral hemisphere during reading and drawing.

2. Good readers at the Grade 3 level will not display cerebral asymmetry during verbal tasks but they will display cerebral asymmetry during spatial tasks.

   a) There will be no difference between EEG alpha band power recorded from the left cerebral hemisphere during reading and drawing.

   b) The EEG alpha band power recorded from the right cerebral hemisphere during drawing will be less than that recorded from the same hemisphere during reading.

3. Poor readers at the Grade 6 level will not display cerebral asymmetry during verbal tasks but they will display cerebral asymmetry during spatial tasks.

   a) There will be no difference between EEG alpha band power recorded from the left cerebral hemisphere during reading and drawing.

   b) The EEG alpha band power recorded from the right cerebral hemisphere during drawing will be less than that recorded from the same hemisphere during reading.

4. Good readers at the Grade 6 level will display cerebral asymmetry during both verbal and spatial tasks.

   a) The EEG alpha band power recorded from the left cerebral hemisphere during reading will be less than that recorded from the same hemisphere during drawing.

   b) The EEG alpha band power recorded from the right cerebral hemisphere during drawing will be less than that recorded from the same hemisphere during reading.

CHAPTER III

METHOD AND DESIGN

SUBJECTS

Grade 3 and Grade 6 students from two middle-class Edmonton Public Schools were asked to participate in the present research project. Grades 3 and 6 were chosen to include students in the early and late reading stages. In order to ensure that the sample would include some children with reading problems, only classes which offered the resource room program (remedial reading in a small group setting) were considered. In one of the two schools, only males were asked to participate since the incidence of reading difficulty is higher among boys than girls (Benton, 1975; Rutter, 1978). The following steps were taken in selecting a sample for the study. Ability, achievement and laterality measures were collected for a total of 47 students. Parental consent was then secured for 34 of the 47 students (see Appendix A for the parental consent form). Finally, 6 of the 34 students were eliminated from the study because they received a left greater than right score on the laterality scale (see Appendix F for a copy of this scale). The final sample was composed of 14 Grade 3 (mean age of 9 - 1 years old) and 14 Grade 6 (mean age of 12 - 0 years old) students. There were 9 males and 5 females in the Grade 3 sample and 11 males and 3 females in the Grade 6 sample. Thus, a final sample of 28 students met the criteria stated above.

Chart 1

Population and Sample Size

Grade	Population		Sample		Percent of Total
	Males	Females	Males	Females	
3	16	5	9	5	67%
6	20	6	11	3	54%

The researcher administered the Slosson Intelligence Test (SIT) during the months of May and June, 1981. The Slosson I.Q. test was used because of its ease in administration and because it requires no reading on the part of the examinee. Reliability for the SIT is .97 and it correlates

highly with the Standford-Binet Intelligence Scale -- .90 - .98 (Salvia and Ysseldyke, 1976). In addition, scores from the Edmonton Public School Board Achievement Tests (Reading Decoding, Reading Comprehension, and Mathematics) were collected from the Student Assessment Department. The Edmonton Public School District achievement tests were administered on a group basis by teachers to all Grade 3 and Grade 6 students in the system (May - June, 1981). The reliabilities of Grade 3 and Grade 6 EPS Achievement Tests are as follows:

Reading -- .932 (Grade 3), .945 (Grade 6),
Mathematics -- .88 (Grade 3), .907 (Grade 6)

In order to define low and high reading groups, the scores from the Reading Decoding and Reading Comprehension subtests were summed for the sample students at each grade level and those achieving above the median constituted the high reading group while those falling below the median constituted the low reading group. Descriptive statistics on the average age, I.Q., and achievement measures are presented in Table 1.

TABLE 1

Average Age, Ability, and Achievement Measures of Low and High Readers (Grade 3 and Grade 6)

Ability and Achievement Tests	Low Readers Mean	Low Readers S.D.	High Readers Mean	High Readers S.D.	Mean Difference	T Value
Grade 3 (7 low and 7 high readers)						
Age in Months	110.0	6.03	101.6	6.73	2.4	0.71
Slosson IQ	93.4	9.14	104.0	16.40	-10.6	-1.49
Reading Decoding	49.9	3.58	56.0	1.29	-6.1**	-4.27
Reading Comp.	48.4	10.45	66.1	6.99	-17.7**	-3.73
Decoding Plus Comp.	98.3	12.83	122.1	7.47	-23.8**	-4.25
Mathematics	43.0	9.04	52.9	6.41	-9.9*	-2.35
Grade 6 (7 low and 7 high readers)						
Age in Months	145.3	6.95	141.9	2.85	3.4	1.21
Slosson IQ	100.7	15.99	122.0	7.00	-21.3**	-3.23
Reading Decoding	21.7	7.46	33.9	1.35	-12.2**	-4.24
Reading Comp.	59.4	16.88	83.9	3.34	-24.5**	-3.76
Decoding Plus Comp.	81.1	23.27	117.7	3.55	-36.6**	-4.11
Mathematics	35.6	9.85	41.4	6.00	- 5.8	-1.34

* $\underline{P} < .05$
** $\underline{P} < .01$

For Grade 3 students, significant differences between the low and high reading groups were found for the achievement measures but not for the ability measure. Accordingly, the low group in fact, received a lower average score than the high group on both reading achievement tests. Similarly, Grade 6 students from the low group received a lower average score than the high group on reading and math achievement tests. On the other hand, it should be noted that the average Slosson I.Q. for the Grade 6 low reading group is significantly lower than that of the high reading group ($\underline{P} < .01$). As a result, the difference in intelligence test scores may confound the results of the dependent variable, the average EEG power. However, since Slosson I.Q. scores did not correlate highly with most of the dependent measures (see Appendix B, Table a), I.Q. scores were not covaried out.

Table 2

Average System-wide Achievement Test Scores for All Edmonton Public School System Students and Sampled Students (1980-81)

EPS Achievement Subtests	Total Score	All EPS Students			Sample Students			Mean Difference
		Mean	S.D.	N	Mean	S.D.	N	
Grade 3								
Reading Decoding	63	50.9	7.17	4326	52.9	4.10	14	-2.0
Reading Comp.	77	56.5	12.86	4326	57.3	12.55	14	-0.8
Mathematics	60	48.6	8.78	4321	47.9	9.10	14	0.7
Grade 6								
Reading Decoding	42	29.3	7.11	4331	27.8	8.14	14	1.5
Reading Comp.	98	70.3	15.67	4331	71.6	17.24	14	-1.3
Mathematics	60	43.0	10.86	4331	38.5	8.40	14	-4.5*

* $\underline{p} < .05$

Table 2 presents average achievement test scores for all Grade 3 and Grade 6 students in the system and for the 28 students who participated in the research study. The system-wide norms were included to compare the sample with the entire student population with respect to achievement test scores. Using a conventional T - Test, the only significant difference found in comparing total students with sampled students was for the mathematics subtest of Grade 6 students. On the mathematics subtest, the sampled students received a lower mean score.

TABLE 3

Pearson Correlations between Ability and Achievement Measures for Grade 3 and Grade 6 Students

Grade 3 (n=14)

	Slosson I.Q.	Reading Decoding	Reading Comprehension	Decoding plus Comprehension
Reading Decoding	.575*	-	-	-
Reading Comprehension	.754***	.783***	-	-
Decoding plus Comp.	.733***	.823***	.987***	-
Mathematics	.535*	.624**	.454	.517*

Grade 6 (n=14)

	Slosson I.Q.	Reading Decoding	Reading Comprehension	Decoding plus Comprehension
Reading Decoding	.894***	-	-	-
Reading Comprehension	.866***	.899***	-	-
Decoding plus Comp.	.895***	.953***	.990***	-
Mathematics	.619**	.718**	.802***	.792***

* $\underline{p} < .05$
** $\underline{p} < .01$
*** $\underline{p} < .001$

Correlations between ability and achievement test scores are displayed in Table 3. It can be observed that these correlations are high and positive for both grade levels. Thus, as would be expected, ability and achievement tests are measuring a similar construct.

APPARATUS

The Biocomp 2001 is a device designed to measure and store human psychophysiological parameters. Seven modalities can be measured -- electromygraph, electroencephalograph, peripheral pulse volume, heart rate, skin potential response, skin conductance response, and temperature. Since the Biocomp has four channels, up to four modalities can be measured simultaneously from an individual subject. The apparatus was designed by Hershel Toomim (Biofeedback Research Institute -- Los Angeles, California) for both clinical and research applications in biofeedback. Although the present study used the Biocomp for assessment, the device can be used for biofeedback training purposes since psychophysiological data can be instantaneously "fed back" (visual and auditory feedback) to the subject. For further information on biofeedback theory, research, and practice see Basmajian (1979); Blanchard and Epstein (1978); Gatchel and Price (1979); and Peper, Ancoli, and Quinn (1979).

The "hardware" of the Biocomp 2001 consists of a small television monitor, an Apple II mini-computer, 2 disc drive units, a printer, a sensor module, two telemeter modules that talk to each other, and an assortment of probes and electrodes. The "software" is a diskette program (Telemetered Biocomputer) written by H. Toomim. Operation of the Biocomp 2001 is accomplished by first placing the diskette program into one of the disc drive units. The program is then started (booted). The subject is then "hooked up" or connected to the apparatus with electrodes and lead wires. Electrodes pick up the psychophysiological activity from the subjects; in this case, electrical activity of the brain. After making a number of minor adjustments, data are then picked up by the electrodes and sent to the sensor module which relays the information to a remote telemeter. The sensor module is the "slave" of the computer. In effect, the computer tells the sensor module what measurements to make. The sensor module is electrically connected to lead wires and electrodes on one side and a remote telemeter on the other side.

Information is transmitted from the remote telemeter to another telemeter that is connected to the Apple II computer. The remote telemeter is electrically connected to the individual and the other telemeter is electrically connected to the computer. As a result, the remote telemeter transmits the signal from the subject and the other telemeter receives the signal. The two telemeters "talk to each other" through the use of an infra-red light. Finally, the information is received into the memory of the computer and displayed on the CRT television screen as an auditory signal is played back through a speaker in the computer. Psychophysiological data from the subject can be stored on the diskette and printed on a hard copy. Details on the technical specifications of the Biocomp 2001 are presented in Appendix C.

For the purposes of the present study, only the EEG modality was used. The Biocomp 2001 EEG system is designed to measure root mean square values from four EEG bandwidths -- theta (4 - 7 cps), alpha (7 - 13 cps), beta (13 - 30 cps), and wide (4 - 30 cps). The alpha bandwidth (7 - 13 cps) was selected because it is most sensitive to EEG amplitude fluctuations in response to cognitive activity (Doyle et al, 1974). Finally, the Biocomp 2001 collected, in this case, EEG alpha amplitude data 15 times each second.

The device described above has been available for clinical and research purposes for only one year. As a result, it has not been used in a variety of experimental settings and its reliability is subject to question. This is especially true of the EEG modality. Therefore, corroborative studies using the Biocomp 2001 are of utmost importance.

PROCEDURE

The present section on procedure will include information on stimulus materials, experimental conditions, electrode placements, and the sequence of experimental steps. Information pertaining to experimental variables, the statistical analysis, and limitations/delimitations of the research study will follow.

Stimulus Materials and Experimental Conditions

Verbal and nonverbal materials were used as stimuli. The verbal materials consisted of passages taken from Grade 3 (Ginn Basic Readers) and Grade 6 (Young Canada Readers) reading texts. The nonverbal materials were nonmeaningful designs taken from the Visual Sequential Memory subtest of the Illinois Tests of Psycholinguistic Abilities (Kirk, McCarthy, & Kirk, 1968), the Visual Memory Test (Wepman, Morency, & Seidl , 1975), and the Memory for Designs Test (Graham & Kendall, 1960). Samples of reading passages and nonmeaningful designs can be found in Appendix D.

The present research study involved three conditions: read, draw, and rest. For the reading condition, subjects were asked to orally read from a passage. The drawing condition consisted of copying various nonmeaningful designs. And for the resting condition, subjects were asked to look at a blank sheet of paper and to think of nothing. Each condition lasted for a period of 90 seconds during which time the EEG was recorded.

Electrode Placement

The bipolar electrode placement procedure was used for the present study. As stated by Andreassi (1980), "when using a bipolar recording technique, two active electrodes are placed over cortical areas of interest. Bipolar leads record the difference or algebraic sum of the electrical potentials beneath the two regions at every instant (p. 33)." The

two active electrodes filled with conductive paste were placed over Wernicke's area (W1) and the angular gyrus (P3) in the left hemisphere and the corresponding areas (W2, P4) in the right hemisphere. In addition, a ground electrode was placed on the left or right forehead (FP1, FP2). The parietal (P3, P4) and frontal (FP1, FP2) locations are according to the international 10-20 system (Jasper, 1959). However, the temporal location (W1, W2) is a revision of the 10-20 system by Matsumiya (1976). That is, the W1 location is defined as the center of a triangle made by 10-20 system locations P3, T3, T5 and the W2 location is defined as the center of a triangle made by 10-20 system locations P4, T4, T6. The sites of Wernicke's area and the left angular gyrus were selected because of their presumed involvement in processing linguistic information.

Procedural Steps

The experiment was conducted in an office at the University of Alberta during June and July, 1981. Each subject was seen individually by the researcher. Parents were invited to remain in the office with their child and, in most cases, did so. The experimental procedure included the following six steps:

1. explanation of the apparatus,
2. electrode placement,
3. display of graphics and sound,
4. instrument test,
5. EEG recording during cognitive activities,
6. explanation of research purpose.

Elaboration of each step is presented below.

A brief explanation and demonstration of the Biocomp 2001 was offered at the beginning of each session. Then electrodes were filled with conductive paste and placed on either the left or right hemisphere of the subject. For 14 of the 28 subjects, recordings were first taken from the left hemisphere and then from the right and recordings were first taken from the right hemisphere for the

other 14 subjects. Subjects were then shown a graphic display of EEG activity recorded by the Biocomp 2001 and they listened to an auditory signal. This was done to help adjust to the experimental setting. In order to test the instrument, subjects were asked to open and close their eyes. The EEG recording was as expected for all subjects (i.e., greater amplitude during eyes closed than during the eyes open state). The actual experiment was conducted next. Subjects were asked to orally read, to copy designs, and to rest. There were two trials for each condition. Thus, subjects read, drew, and rested for a total of four times each (two times during left hemisphere recordings and two times during right hemisphere recordings for each condition). Each condition lasted exactly 90 seconds. The order of conditions was systematically altered to prevent sequence effects. Six separate sequences were used (see Appendix F). At the end of each recording epoch, the apparatus was programmed to store the data on a diskette and to print the data on a hard copy for subsequent analysis.

For each condition, subjects were given the following instructions, verbatim:

> Reading Condition -- Here is a story about ____________________. I want you to read it out loud to me. If you have trouble with any of the words, I will help you. Try to concentrate on what the story is about while you read it. When I say "begin", start reading the story and when you hear a beep (about 90 seconds later) you may stop.
>
> Drawing Condition -- Do you see these designs? They look kind of funny. But they are not meant to be pictures of anything. I would like you to copy them on this sheet of paper. Don't worry if you make mistakes. While you are copying the designs I want you to think only of these figures. Do not talk to me or think about anything else. I will tell you when to begin and you can stop when you hear a beep.
>
> Resting Condition -- I am going to ask you to do something that is kind of hard to do. Listen very carefully. I want you to relax, look at this blank piece of paper, and think of nothing. Yes, I want you to clear your mind of all thoughts. That is the hard part. See this piece of paper? There is nothing on it, right? Well, I would like you to have nothing on your mind, just like this piece of paper has nothing on it. Now sit back and relax, get comfortable and start looking at the piece of paper. When you hear the beep you may stop resting.

After the 12 epochs were recorded, subjects were disconnected from the Biocomp 2001. Finally, the parents and subjects were informed of the purpose and rationale of the study. Each session lasted approximately one hour.

EXPERIMENTAL VARIABLES AND STATISTICAL ANALYSIS

The dependent variable of the present study was average EEG alpha amplitude measured in microvolts. Amplitude is a measure of the size of the electrical signal. The Biocomp 2001 output for each 90 second epoch consisted of 36 averaged amplitude (root mean square) recordings. In order to reduce artifact associated with initial fluctuations and to reduce the large number of data (432 data points for each subject), the final 10 data points were averaged for each condition. As a result, 12 averaged amplitude recordings (4 for each condition) were used for subsequent analysis. Independent variables were reading group, hemisphere and condition or cognitive task.

The statistical technique used for data analysis was a 2 x 2 x 3 ANOVA with repeated measures on the last two factors. The first factor was reading group (low readers and high readers), the second factor was hemisphere (left and right), and the third factor was a cognitive task (read, draw, and rest). A separate ANOVA was run for each grade level (3 and 6) and for each trial (1 and 2). Thus, four separate ANOVA's were run for the general model. In addition, the Scheffe' method was used for making a posteriori comparisons of means. Finally, a number of Pearson Product-Moment Correlations between hemispheres, trials, and tasks were calculated. These correlations are presented in Tables b, c, and d (Appendix B).

Information from Scheffe' multiple comparisons is most directly related to the hypotheses to be tested. However, statistically significant main effects and interaction effects from the ANOVAs are also included in the analysis. These effects are less specific than the statistically significant Scheffe' comparisons but they help to explain the results in a more general sense (e.g. across groups, hemispheres, or tasks).

LIMITATIONS AND DELIMITATIONS

Prior to presenting and discussing results, it is important to acknowledge problems and limit the scope of the present study. Major limitations pertain to artifact, the I.Q. confound, and the selection procedure. As stated previously in the review of literature and research, both physiological and instrumental artifacts are present in EEG research studies. For example some instrumental artifacts are caused by batteries, switches, plugs, sockets, wiring, resistors, and capacitors. In addition, since the Biocomp 2001 transmits the signal from one telemeter to another, this signal is subject to "noise" in the atmosphere. Common psychophysiological artifacts are arousal (GSR), muscle tension (EMG), heart rate (ECG), and eyeblinks (EOG). See Shagass (1972) for further information on EEG artifacts. The second limitation is the fact that the Grade 6 poor readers scored significantly lower on the Slosson I.Q. test than the normal Grade 6 readers. On the other hand, there is typically a high correlation between ability and achievement test scores. Intelligence test performance then may confound the results. And, third, that subjects were not randomly selected from a large pool is a definite limitation since this is an assumption of the ANOVA technique.

The scope of the present study is subject to four delimitations. First, even though the average reading achievement score of the low reading group is significantly lower than that of the high group for both grades (see Table 1), the low reading group was not conventionally defined as reading disabled. As a result, findings from the study cannot be applied to reading disabled children in comparison to normal readers. This delimitation then is that subjects selected for the study differ in reading achievement -- some are better than others. Second, the low number of subjects and the selection procedure preclude generalization. Third, the poor readers were not subtyped according to differential deficiencies in reading subskills and, hence, this limits the scope in terms of specificity. Incidently, the low readers were not subgrouped due to the consequences of delimitations 1 and 2. Finally, the forth delimitation is that only alpha power was examined. Consequently, it is not known what

relationships exist between reading and drawing for the low and high readers in other frequency bands. It is essential to be aware of these limitations and delimitations in interpreting the results which are presented in the next chapter.

CHAPTER IV

RESULTS

The mean EEG alpha amplitude data were analyzed in three different ways using the classical ANOVA technique. First, the means were analyzed using the "General Model." For this particular model, four separate 2 x 2 x 3 ANOVA's were calculated -- one for each trial at both grade levels. Second, the means were analyzed using the "Compostie Model (Trial 1 plus Trial 2)". Here two 2 x 2 x 3 ANOVA's were calculated -- one for each grade level summed over the two trials. And, third, the means were analyzed using the "Task minus Rest Model" in which the absolute value of the difference between the rest and task (reading and drawing) conditions was the dependent variable. Four separate 2 x 2 x 2 ANOVA's were calculated for the "Task minus Rest Model" -- one for each trial at each grade level. The task minus rest model was calculated in order to analyze the task-related conditions as differences from EEG baseline (rest condition). Moreover, such a procedure would minimize the effect of individual differences impinging on the psychophysiological measures.

Results will be presented then according to the three models outlined above. Information on the Grade 3 sample will be presented first to be followed by information on the Grade 6 sample for each model. Summary ANOVA and contrast tables can be found in Appendix E (Tables e - x). Mean differences are considered statistically significant if the probability of finding such a difference by chance is less than 5%. Prior to presenting results from the ANOVA's, comments will be made regarding correlations between trials, hemispheres, and tasks.

Pearson correlations between trials (trial 1 and trial 2), between hemispheres (left and right), and between tasks (read, draw, rest) are presented in Appendix B (Tables b, c, and d). Three findings are relevant: 1) correlations between trials are high and positive (Table b); 2) correlations between hemispheres are positive, some of which are high (Table c); and 3) correlations between tasks are high and positive (Table d). This latter finding is a bit unexpected since one would expect the EEG amplitude

distribution to be different for each of the tasks. The raw data from the experiment are presented in Tables 4 - 7.

TABLE 4

Raw Data of EEG Amplitude (microvolts) during Reading, Drawing, and Resting Tasks: Grade 3-Trial 1

Subjects	Left Hemisphere			Right Hemisphere		
	Read	Draw	Rest	Read	Draw	Rest
Low Readers						
1	3.1	6.2	6.3	3.6	3.4	3.1
2	6.8	6.9	4.1	5.7	5.2	4.9
3	3.6	4.2	3.8	4.0	3.9	11.0
4	2.7	3.9	2.6	2.7	2.9	2.7
5	4.1	3.7	3.8	7.4	5.6	4.8
6	3.2	3.4	3.6	7.6	6.5	3.8
7	1.2	1.2	1.2	6.8	5.3	6.7
High Readers						
8	6.2	7.1	5.4	13.5	15.8	9.4
9	4.3	3.2	3.5	4.5	9.9	1.2
10	5.6	4.9	4.3	3.4	3.6	3.5
11	3.5	3.9	1.8	4.1	3.3	4.6
12	2.3	2.0	2.8	3.3	3.0	3.4
13	3.0	3.0	2.7	3.1	3.1	2.7
14	3.7	3.6	4.9	4.0	3.7	2.8

TABLE 5

Raw Data of EEG Amplitude (microvolts) during Reading, Drawing, and Resting Tasks: Grade 3 - Trial 2

	Left Hemisphere			Right Hemisphere		
Subjects	Read	Draw	Rest	Read	Draw	Rest
Low Readers						
1	1.8	2.0	1.3	3.7	3.7	3.1
2	5.8	7.4	5.0	5.9	5.4	4.6
3	3.6	3.6	3.2	5.6	4.4	3.5
4	3.1	3.1	2.1	2.8	2.5	2.3
5	3.9	3.7	4.2	6.0	5.5	4.3
6	3.2	3.4	3.0	6.2	5.7	3.6
7	1.3	1.1	1.2	3.4	6.5	3.2
High Readers						
8	6.0	8.5	3.3	11.1	13.1	8.8
9	3.1	2.7	2.1	2.9	2.5	3.3
10	6.0	5.0	3.2	3.7	3.2	3.2
11	4.0	3.1	3.2	4.0	4.1	3.1
12	2.4	2.4	2.4	3.5	3.2	2.9
13	2.9	2.9	2.9	3.0	3.0	2.7
14	3.8	4.0	3.7	5.5	3.7	3.7

TABLE 6

Raw Data of EEG Amplitude (microvolts) during Reading, Drawing, and Resting Tasks: Grade 6 - Trial 1

Subjects	Left Hemisphere			Right Hemisphere		
	Read	Draw	Rest	Read	Draw	Rest
Low Readers						
1	6.8	3.3	3.0	13.0	2.4	2.2
2	3.3	3.5	2.5	4.4	4.3	3.3
3	2.9	3.8	2.6	3.5	3.4	3.3
4	2.4	2.1	1.8	3.8	3.2	2.3
5	2.8	5.9	2.9	2.0	2.1	4.0
6	3.7	1.9	1.7	3.7	3.6	3.2
7	2.7	4.7	2.7	7.7	7.4	3.6
High Readers						
8	3.4	2.6	3.1	3.9	3.9	7.6
9	5.5	6.1	6.3	4.9	6.0	6.9
10	10.4	10.1	7.7	4.8	7.7	12.5
11	7.8	6.9	4.8	5.5	5.6	4.6
12	2.9	2.9	2.4	6.3	10.6	8.4
13	5.6	5.0	4.8	16.8	5.2	5.4
14	3.2	6.4	4.3	4.0	3.9	3.8

TABLE 7

Raw Data of EEG Amplitude (microvolts) during Reading, Drawing, and Resting Tasks: Grade 6 - Trial 2

Subjects	Left Hemisphere			Right Hemisphere		
	Read	Draw	Rest	Read	Draw	Rest
Low Readers						
1	4.6	3.4	3.0	5.8	4.3	4.0
2	3.2	3.7	3.4	4.5	4.4	3.0
3	3.2	3.7	3.2	3.7	3.3	3.3
4	3.2	2.1	1.9	4.0	3.0	2.0
5	2.1	2.4	2.4	2.0	1.9	1.8
6	1.7	2.0	1.9	3.6	3.0	3.2
7	5.0	3.3	4.9	7.0	7.3	7.5
High Readers						
8	3.2	2.9	2.9	3.6	3.0	6.6
9	5.9	4.9	4.8	7.6	5.0	6.5
10	12.6	10.5	8.7	4.1	10.6	10.7
11	7.5	7.8	4.9	4.6	4.5	3.5
12	2.6	3.6	2.4	13.6	10.7	16.4
13	6.6	6.7	5.2	12.1	3.7	6.2
14	3.0	3.6	3.9	3.8	3.7	3.5

Presented below in Chart 2 is a tabular representation of the hypotheses to be tested. In essence, Chart 2 displays the expected relationships between reading and drawing with respect to the dependent variable (i.e., average EEG alpha amplitude). See Chapter II (pp. 90 - 91) for verbal statements of the hypotheses.

Chart 2

Expected Relationship between Alpha Amplitude values of Reading and Drawing as Stated in the Hypotheses to be Tested

Reading Group	Hemisphere	
	Left (Hypothesis)	Right (Hypothesis)
Grade 3		
Poor Readers	Read = Draw (1a)	Read = Draw (1b)
Good Readers	Read = Draw (2a)	Read > Draw (2b)
Grade 6		
Poor Readers	Read = Draw (3a)	Read > Draw (3b)
Good Readers	Read < Draw (4a)	Read > Draw (4b)

THE GENERAL ANOVA MODEL

Grade 3 Results

The mean EEG alpha amplitudes recorded during reading, drawing, and resting are displayed in Table 8. Table 9 shows significant differences between hemispheres and tasks using the Scheffe' multiple comparison method.

TABLE 8

Mean EEG Alpha Amplitudes (microvolts) of Grade 3 Students

Reading Group (n)	Left Hemisphere			Right Hemisphere		
	Read	Draw	Rest	Read	Draw	Rest
Trial 1						
Low (7)	3.53	4.21	3.63	5.40	4.69	5.29
High (7)	4.09	3.96	3.63	5.13	5.01	3.94
Trial 2						
Low (7)	3.24	3.47	2.86	4.80	4.81	3.51
High (7)	4.03	4.09	2.97	4.81	4.69	3.96

TABLE 9

Significant Differences Using Scheffe' Comparisons for Grade 3 Students

Description of Results	Mean Diff.	DF	F	P Level
Trial 1				
Right draw > right rest for high group	2.07	2,24	13.23	.01
Trial 2				
Left read < right read for low group	1.56	2,36	9.70	.05
Left draw < right draw for low group	1.34	2,36	7.21	.05
Right read > right rest for low group	1.29	2,24	16.54	.01
Right draw > right rest for low group	1.30	2,24	16.90	.01
Left read > left rest for high group	1.06	2,24	11.19	.01
Left draw > left rest for high group	1.12	2,24	12.43	.01
Right read > right rest for high group	0.85	2,24	7.34	.05

For each trial subjects read, drew, and rested for a period of 90 seconds each during which electrical activity was recorded using the Biocomp 2001. Trial 1 then constituted the initial 270 seconds of EEG recordings and Trial 2 constituted the remaining 270 second recordings for each hemisphere. Results will be presented for each separately.

Trial 1. The analysis of variance indicated a significant main effect for hemispheres, $F = 3.9$, $P = .09$ (Table e in Appendix E). In general, higher alpha amplitudes were recorded from the right hemisphere ($\overline{X} = 5.08$) then the left ($\overline{X} = 3.84$). This finding would indicate that, in general, the left hemisphere was more active than the right. That is, regardless of task (reading, drawing, resting) or group (low, high readers), the left hemisphere was more involved in processing information than the right. As displayed in Table f (Appendix E), two contrasts attained statistical significance:

1. High draw > high rest ($F = 6.67$, $P = .02$)
2. Left read < right read ($F = 4.81$, $P = .04$)

Hence, there was greater activation for high readers during the resting condition than during drawing. And during reading, the left hemisphere of Grade 3 subjects was more active than the right. The individual comparisons using the Scheffe' method (Table 9) yielded only one significant finding -- the high reading group showed more activation during rest than drawing on the right hemisphere. In other words, the right hemisphere of the high reading group was more actively involved in processing information during resting than during drawing tasks.

Trial 2. For Trial 2, a main effect was found with respect to the task or condition factor, $F = 8.28$, $P = .002$ (Table g). Means for reading, drawing, and resting were 4.22, 4.26, and 3.33 respectively. Thus, this finding would indicate that there was greater activation during the resting condition than during either reading or drawing. Such a finding is not according to expectation since resting was considered to be a

task which would require little cognitive effort in comparison to reading or drawing. Hence, the average EEG alpha amplitude for resting was expected to be significantly higher than that for either reading or drawing. Regarding the summary of contrasts table (Table h), the following comparisons resulted in statistically significant differences:

1. Low read > low rest (F = 7.71, P = .01),
2. Low draw > low rest (F = 10.11, P = .004),
3. High read > high rest (F = 10.11, P = .004),
4. High draw > high rest (F = 9.37, P = .01),
5. Left read < right read (F = 8.21, P = .01),
6. Left draw < right draw (F = 5.65, P = .02),
7. Left read > left rest (F = 5.21, P = .03),
8. Left draw > left rest (F = 7.48, P = .01),
9. Right read > right rest (F = 11.49, P = .001)
10. Right draw > right rest (F = 10.30, P = .002).

According to these comparisons, results 1 - 4 and 7 - 10 indicate that there was greater activation during resting than reading or drawing. It should be noted that results 5 and 6 indicate that the left hemisphere was more active than the right during reading and drawing. This finding then would suggest that hemispheric specialization is not occuring for different tasks since the left hemisphere is more active for both tasks (reading and drawing) compared to the right. According to Table 9, both low and high groups displayed greater activation during the resting condition but only the low group displayed greater activation on the left hemisphere as compared to the right.

Summary. As stated in Hypothesis 1 it was expected that low readers would not display hemispheric specialization for either verbal or spatial tasks. Since statistically significant findings were not found regarding average alpha amplitude differences between reading and drawing for both the left and right hemispheres, Hypotheses 1a and 1b are supported by the results. With respect to Hypothesis 2 (high reading group), it was

expected that cerebral asymmetry would also not be found for the verbal tasks but that it would occur for spatial tasks. Hypothesis 2a is supported by the results because no statistically significant results were found regarding the average alpha amplitude differences between reading and drawing recorded from the left hemisphere. However, Hypothesis 2b was not confirmed because EEG alpha band power recorded from the right cerebral hemisphere during drawing was not significantly lower than that recorded from the left hemisphere during reading tasks for the high reading group. In sum, hemispheric specialization for spatial tasks as suggested by Hypothesis 2b was not confirmed by the results.

Grade 6 Results

The mean alpha amplitudes recorded during reading, drawing, and resting for Grade 6 students are displayed in Table 10. Statistically significant findings from the Scheffe' multiple comparisons method are shown in Table 11.

TABLE 10

Mean EEG Alpha Amplitudes (microvolts)
of Grade 6 Students

	Left Hemisphere			Right Hemisphere		
Reading Group (n)	Read	Draw	Rest	Read	Draw	Rest
Low (7)	3.51	3.60	2.46	5.44	3.77	3.13
High (7)	5.54	5.71	4.77	6.60	6.13	7.03
Low (7)	3.29	2.94	2.96	4.37	3.88	3.54
High (7)	5.91	5.71	4.69	7.06	5.89	7.63

TABLE 11

Significant Differences Using Scheffe'

Comparisons for Grade 6 Students

Description of Results	Mean Diff.	DF	F	P Level
Trial 1				
Low rest < high rest on right hemisphere	3.90	2,36	14.21	.01
Left rest < right rest for high group	2.26	2,36	7.18	.05
Trial 2				
Low read < high read on right hemisphere	2.69	2,36	6.56	.05
Low draw < high draw on left hemisphere	2.77	2,36	6.98	.05
Low rest < high rest on right hemisphere	4.09	2,36	15.18	.01
Left rest < right rest for high group	2.94	2,36	9.12	.05

Trial 1. A significant main effect from the analysis of variance was found for the group factor, F = 10.34, P = .01 (Table i in Appendix E). In general, the alpha amplitude average was higher for the high reading group ($\bar{X}$ = 5.96) than for the low reading group (3.65). This would indicate that, in general, the low reading group displayed greater activation than the high reading group. Stated another way, perhaps the low reading group had to expend more "cognitive energy" to complete the tasks in comparison to the high reading group. Contrasts which attained statistical significance are as follows (Table j in Appendix E):

1. Low right < high right (F = 4.85, P = .04),
2. Low draw < high draw (F = 7.02, P = .01),
3. Low rest < high rest (F = 13.54, P = .001),
4. Low read > low rest (F = 5.15, P = .03),
5. Left read < right read (F = 4.72, P = .04),
6. Left rest < right rest (F = 4.54, P = .04).

Recall that low and high refer to the low and high reading groups; left and right refer to the left and right hemispheres; and read, draw, and rest refer to the three experimental tasks.

Findings 1 - 3 indicate the greater activation of the low group on the right hemisphere and during drawing and resting. Finding 4 shows that the low group was less activated during reading than resting. This finding is not according to expectation since the reading task should require more cognitive involvement than the resting task. And, findings 5 and 6 indicate that the left hemisphere was more active than the right during reading and resting conditions. That is, the left hemisphere was involved in information processing to a greater extent than the right for reading and resting tasks. Finally, individual comparisons (Table 11) resulted in two statistically significant findings: 1) greater activation for the low group compared to the high group during resting on the right hemisphere, and 2) greater activation on the left hemisphere than the right during resting for the high group.

Trial 2. The effect for groups was found to be statistically significant, $F = 7.62$, $P = .02$ (Table k). Accordingly, the low group was more activated than the high group (means of 3.50 and 6.15, respectively). The following four contrasts attained statistical significance (Table 1):

1. Low read $<$ high read ($F = 9.65$, $P = .004$),
2. Low draw $<$ high draw ($F = 7.78$, $P = .01$),
3. Low rest $<$ high rest ($F = 11.55$, $P = .002$),
4. Left rest $<$ right rest ($F = 4.90$, $P = .03$).

Thus, the low reading group displayed greater activation during all three conditions and the left hemisphere was more active than the right during the resting condition. According to the Scheffe' individual comparisons (Table 11), this latter result reached statistical significance for only the high reading group. In addition, the low readers displayed more activation than the high readers for both reading and resting conditions on the right hemisphere. Finally, the low readers displayed more activation than the high readers during drawing recorded from the left hemisphere.

Summary. According to Hypothesis 3, low readers were expected to show cerebral asymmetry for spatial tasks (3b) but not for verbal tasks (3a). Since average alpha amplitude measures were not significantly different between reading and drawing tasks as recorded from the left hemisphere, Hypothesis 3a is supported by the results. But Hypothesis 3b was not confirmed because the average EEG measures during drawing were not significantly lower than those during reading recorded from the right hemisphere. With reference to Hypothesis 4 (high reading group), neither Hypothesis 4a nor Hypothesis 4b were supported by the results. That is, no statistical differences were found between reading and drawing alpha amplitudes recorded from either the left or right hemisphere of the high reading group. In sum, neither the low nor the high reading group displayed hemispheric specialization as suggested by Hypothesis 3b and 4a & b.

Summary of Results (General Model)

In general, the left hemisphere was more active than the right and more activity was displayed for the resting condition than during reading or drawing for Grade 3 subjects. The Grade 6 low reading group displayed more activity than the Grade 6 high readers. Greater cognitive activity is inferred from lower alpha amplitude values. Regarding the finding of greater alpha amplitude in the right hemisphere, McKee et al (1973) and Morgan et al (1971) reported similar results. These results neither support nor refute the construct of hemispheric specialization. There were no significant differences found between reading and drawing for either reading group at each grade level. Therefore, Hypothesis 1a, 1b, 2a, and 3a are supported by the results. This is stated because these hypotheses predict that cerebral asymmetry will not be found. However, since Hypothesis 2b, 3b, 4a and 4b (see Chart 2) predict differences between reading and drawing, they were not confirmed by the results. Therefore, evidence of hemispheric specialization was not found using the general ANOVA model. Results from the Composite 2 x 2 x 3 ANOVA model (Trial 1 plus Trial 2) are presented next. Trial 1 and Trial 2 were summed in order to observe composite main and interaction effects.

THE COMPOSITE ANOVA MODEL (TRIAL 1 PLUS TRIAL 2)

Grade 3 Results

The composite (Trial 1 plus Trial 2) means of EEG alpha amplitude recorded during reading, drawing, and resting conditions are presented in Table 12. In addition, Table 13 displays significant differences found using the Scheffe' multiple comparison method.

TABLE 12

Mean EEG Alpha Amplitudes (microvolts)
of Grade 3 Students (Trial 1 plus Trial 2)

Reading Group (n)	Left Hemisphere			Right Hemisphere		
	Read	Draw	Rest	Read	Draw	Rest
Low (7)	3.40	3.84	3.26	5.11	4.77	4.43
High (7)	4.09	4.04	3.31	5.00	5.37	3.99

TABLE 13

Significant Differences Using Scheffe'
Comparisons for Grade 3 Students (Trial 1 plus Trial 2)

Description of Results	Mean Diff.	DF	F	P Level
Left read < right read for low group	1.71	2,36	8.39	.05
High read > high rest on right hemisphere	1.01	2,24	6.85	.05
High draw > high rest on right hemisphere	1.38	2,24	12.79	.01

According to Table m (Appendix E), a main effect for the task factor was found significant, $F = 4.49$, $P = .02$. The means for reading, drawing, and resting were, 4.40, 4.51, and 3.75, respectively. The main effect is due to the lower amplitude recording (greater activation) for the resting condition. Statistically significant contrasts for the Grade 3 composite model, as recorded in Table n (Appendix E) are as follows:

1. High read $>$ high rest ($F = 7.92$, $P = .01$),
2. High draw $>$ high rest ($F = 11.10$, $P = .003$),
3. Left read $<$ right read ($F = 7.32$, $P = .01$),
4. Left draw $<$ right draw ($F = 5.40$, $P = .03$),
5. Right read $>$ right rest ($F = 5.95$, $P = .02$),
6. Right draw $>$ right rest ($F = 6.15$, $P = .02$).

According to findings 1, 2, 5, and 6, resting is a greater activated condition than reading or drawing for the high group and recorded from the right hemisphere. Also, findings 3 and 4 would indicate that the left hemisphere of the Grade 3 subjects was more activated than the right during both reading and drawing. As displayed in Table 13, this latter finding was statistically significant for the low group during the reading condition. This means that the left hemisphere was more involved in reading than the right hemisphere of the low reading group. Other individual comparisons confirm that resting was the greater activated condition for the high reading group and recorded from the right hemisphere.

Grade 6 Results

Table 14 displays the composite means of EEG alpha amplitude for Grade 6 subjects. And the statistically significant differences found using the Scheffe' multiple comparison method are presented below in Table 15.

TABLE 14

Mean EEG Alpha Amplitudes (microvolts)

of Grade 6 Students (Trial 1 plus Trial 2)

Reading Group (n)	Left Hemisphere			Right Hemisphere		
	Read	Draw	Rest	Read	Draw	Rest
Low (7)	3.43	3.30	2.73	4.93	3.86	3.36
High (7)	5.74	5.74	4.74	6.87	6.04	7.34

TABLE 15

Significant Differences Using Scheffe'

Comparisons for Grade 6 Students (Trial 1 plus Trial 2)

Description of Results	Mean Diff.	DF	F	P Level
Low rest < high rest on right hemisphere	3.98	2,36	17.08	.01
Left rest < right rest for high group	2.60	2,36	9.66	.05

The only significant main effect was found for the group factor, $\underline{F} = 9.44$, $\underline{P} = .01$ (see Table o in Appendix B). The mean amplitude value of the low group (3.60) was lower than that of the high group (6.08). Hence, the low group was more activated than the high group. A number of statistically significant contrasts, as recorded in Table p, were found:

1. low right < high right (F = 4.35, $\underline{P}$ = .048),
2. low read < high read ($\underline{F}$ = 7.34, $\underline{P}$ = .01),
3. low draw < high draw ($\underline{F}$ = 8.68, $\underline{P}$ = .01),
4. low rest < high rest ($\underline{F}$ = 14.59, $\underline{P}$ = .001),
5. low read > low rest ($\underline{F}$ = 4.72, $\underline{P}$ = .04),
6. left rest < right rest ($\underline{F}$ = 5.57, $\underline{P}$ = .02).

Stated differently, the low group displayed greater activation than the high group during all conditions and, in general, recorded from the right hemisphere. In addition, reading was a lesser activated condition than resting for the low group and, during resting, the left hemisphere was more activated than the right. Finally, Scheffe' comparisons (Table 15)

resulted in two statistically significant findings: 1) the low group displayed greater activation than the high group during resting as recorded from the right hemisphere, and 2) the left hemisphere of the high group was more activated than the right during resting.

Summary of Results (Composite Model)

In general, resting was a more active condition than reading or drawing (Grade 3) and the low group was more activated during the experiment than the high group (Grade 6). Again, significant differences were not found regarding comparisons between reading and drawing. In other words, evidence of hemispheric specialization as set forth in the hypotheses (see Chart 2) was lacking. As a result, the influence of resting will be removed by subtracting it from both reading and drawing for each subject. This manipulation will then serve to highlight the relationship between reading and drawing. Results from the "Task Minus Rest Model" follow.

THE TASK MINUS REST ANOVA MODEL

Grade 3 Results

For the Task Minus Rest Model, first the absolute value of the difference between means (reading and resting, drawing and resting) was calculated for each subject. The resulting differences were entered into the analysis of variance program as raw data. In total, four 2 x 2 x 2 (groups by hemispheres by tasks) ANOVA's with repeated measures on the latter two factors were produced (one for each trial at each grade level). The means (alpha amplitude) for Grade 3 subjects are presented in Table 16.

TABLE 16

Mean EEG Alpha Amplitudes (microvolts)

of Grade 3 Students (Task Minus Rest)

Reading Group (n)	Left Hemisphere Read	Left Hemisphere Draw	Right Hemisphere Read	Right Hemisphere Draw
Trial 1				
Low (7)	0.49	0.70	2.11	1.83
High (7)	0.94	1.01	1.39	2.56
Trial 2				
Low (7)	0.47	0.79	1.29	1.30
High (7)	1.06	1.14	0.97	0.96

A note of caution is required prior to the reporting of results. Since the absolute value of the difference between task and rest was taken as the dependent variable, the results do not offer information on the differential involvement of the hemispheres during reading and drawing conditions. That is, comments pertaining to cognitive activation cannot be made on the basis of the task minus rest analysis of variance. Thus, the purpose of this model is only to highlight differences between the two task-related conditions and a resting baseline. The direction of these differences, if they are found, is unknown.

Trial 1 and Trial 2. According to Tables q, r, s, and t, there were neither significant main effects nor significant contrasts for the Grade 3 subjects. Accordingly, there were no statistically significant differences both between and within reading and drawing conditions with the resting baseline (eyes open) subtracted from each task.

Grade 6 Results

The alpha amplitude means for the task minus rest ANOVA's of Grade 6 subjects are presented in Table 17. Also, significant differences between means using the Scheffe' multiple comparison method are displayed in Table 18.

TABLE 17

Mean EEG Alpha Amplitudes (microvolts)

of Grade 6 Students (Task Minus Rest)

Reading Group (n)	Left Hemisphere		Right Hemisphere	
	Read	Draw	Read	Draw
Trial 1				
Low (7)	1.09	1.14	2.89	1.19
High (7)	1.31	1.14	4.00	1.84
Trial 2				
Low (7)	0.53	0.44	0.97	0.46
High (7)	1.49	1.11	2.97	2.09

TABLE 18

Significant Differences Using Scheffe'

Comparisons for Grade 6 Students (Task Minus Rest)

Description of Results	Mean Diff.	DF	F	P Level
Trial 1				
Left read right read for low group	1.80	1,24	1.80	.05
Left read right read for high group	2.69	1,24	13.16	.01
Right read right draw for high group	2.16	1,24	6.96	.05
Trial 2				
Low read high read on right hemisphere	2.00	1,24	12.40	.01
Low draw high draw on right hemisphere	1.63	1,24	8.56	.05
Left read right read for high group	1.48	1,24	6.89	.05

Trial 1. In reference to Table u, a significant main effect for hemispheres was found, $F = 5.03$, $P = .045$. The mean of the left hemisphere (1.17) was lower than that of the right hemisphere (2.48). That is, greater difference from a resting baseline was found on the right hemisphere. The following contrasts, as reported in Table v, reached statistical significance:

1. Left read $<$ right read ($F = 9.15$, $P = .01$)
2. Right read $>$ right draw ($F = 5.52$, $P = .03$)

In other words, the greater difference from baseline found on the right hemisphere as compared to the left was largely due to the reading condition. Also, regarding the right hemisphere, there was greater difference from resting for reading than for drawing. Finally, the first significant contrast (above) was found for both groups, whereas the second was found only for the high group (see Table 18).

Trial 2. The main effect for the group factor reached statistical significance, $\underline{F} = 10.77$, $\underline{P} = .01$. Accordingly, the mean for the low reading group (0.60) was significantly lower than that for the high group (1.91). This finding would indicate that a greater difference from baseline existed for the high group vis à vis the low reading group. Summary contrasts are recorded in Table x (Appendix E). Statistically significant contrasts are as follows:

1. low right < high right ($\underline{F} = 10.61$, $\underline{P} = 0.003$),
2. high left < high right ($\underline{F} = 5.03$, $\underline{P} = 0.045$),
3. low read < high read ($\underline{F} = 7.04$, $\underline{P} = .01$),
4. left read < right read ($\underline{F} = 4.46$, $\underline{P} = .045$).

On the right hemisphere, the low reading group displayed less difference from baseline resting than the high group. Within the high group, the right hemispheric recordings were different from baseline to a greater degree than the left hemispheric recordings. During reading, the low group differed from baseline less than the high group and recordings from the left hemisphere showed less difference from baseline than those from the right. As presented in Table 18, the results from Finding 1 (above) were found for both tasks but Finding 4 was confirmed for only the high group.

Summary of Results (Task Minus Rest Model)

While main effects, contrasts, and individual comparisons for the Grade 3 data failed to reach statistical significance, some statistically

significant results were secured for the Grade 6 data. In general, significant main effects were found for the hemisphere factor and the group factor. These findings would indicate that greater difference from the baseline resting condition was found on the right hemisphere vis à vis the left and for the high group vis à vis the low group. According to Table 17, the greatest difference from baseline occurred on the right hemisphere during reading for the high reading group (a mean value of 4.00 for Trial 1 and 2.97 for Trial 2). Since the task minus rest measures are absolute values, comments on the direction of the differences would be inappropriate. However, for the Grade 3 subjects Hypothesis 1a, 1b, and 2a posit that no differences will be found and, therefore, these seem to be confirmed by the data. Hypothesis 2b was not confirmed. Regarding the Grade 6 data, the only hypothesis that would receive confirmation from the data is Hypothesis 3a.

Discussion of the results reported in the present chapter will be addressed in the next chapter. A major objective will then be to relate the present results to the hypothetical construct of hemispheric specialization. In addition, both theoretical and practical implications for further research will be suggested in the chapter to follow.

CHAPTER V

DISCUSSION AND IMPLICATIONS

The purpose of the present chapter is to propose general interpretations and implications from the study. Regarding interpretations, the main objective is to compare and contrast the results with the notion of hemispheric specialization; particularly as it may relate to reading ability.Regarding implications, a number of directions for further research will be suggested. Here the major focus will be on the interaction between theoretical constructs and applied research. The objective is to determine how the present study could be extended in terms of abstractions and operations.

DISCUSSION AND INTERPRETATION OF FINDINGS

The General Model (Grade 3)

Two overall findings are of interest. First, the left hemisphere was generally more activated than the right. A feasible interpretation of this finding may be that the left hemisphere is engaged more by school-related tasks than the right. In other words, perhaps linguistic-related activities are stressed more than nonlinguistic related activities by the school and, as a result, students learn to use their left hemispheres more than their right hemispheres. Moreover, analytic-sequential processing may receive greater emphasis than holistic-simultaneous processing. A second major finding was that greater activation was displayed for the resting condition than for either the reading or drawing conditions. This finding was opposite from that expected. A partial explanation is that children did not actually rest during the resting condition. Most of the children stated that they felt the resting condition was the hardest and that it bordered on the edge of the impossible. Hence, children may have been unable to "think of nothing".

Although statistically significant differences between reading and drawing on each hemisphere were not found, it may be instructive to examine the direction of the nonsignificant differences displayed. Notice that low readers seemed to activate the left hemisphere more during reading than drawing in comparison to the high reading group (Table 8). An overuse of the left hemisphere during the initial stages of reading acquisition may be dysfunctional (see Bakker 1979b). On the right hemisphere, high readers were consistently (both trials) more activated during drawing than reading. This finding is in congruence with and would offer mild support for Hypothesis 2b, which stated that good readers would be specialized in processing nonverbal information. With respect to low readers, the right hemisphere was more activated during drawing than reading for Trial 1, only. Regarding Trial 2, the right hemisphere was equally activated during reading and drawing. Therefore, the results from Trial 2 are in accordance with Hypothesis 1b (i.e. no specialization for nonverbal tasks).

In conclusion, considering the direction of the amplitude measures (not statistically significant), partial support for Hypothesis 1b and 2b can be gleaned from the results. In addition, Hypothesis 1a and 2a were confirmed but Hypothesis 1a is suspect since the direction of the difference between reading and drawing on the left hemisphere for low readers is relatively large; although not statistically significant. Again, conclusive evidence of hemispheric specialization as predicted is lacking for both the low and the high reading groups.

<u>The General Model (Grade 6)</u>

A consistent (both trials) overall finding for Grade 6 students was that the low group displayed greater activation during the experiment than the high reading group. A plausible interpretation of this finding is that, in general, the low group may have had more difficulty with the three tasks. Thus, the low group would have had to expend more cognitive energy in order to complete the tasks. A significant interaction effect was found for hemisphere X task. That is, the left hemisphere of the subjects was more activated than the right during reading and resting. Again, perhaps elementary school instruction makes greater demand on the left hemisphere than the right.

Turning now to comparisons between reading and drawing for each hemisphere, no significant differences were found. This finding would lend support to Hypothesis 3a (no difference in alpha amplitude between reading and drawing) but it would not confirm Hypothesis 3b, 4a and 4b. Therefore, it may be instructive to examine the data presented in Table 10 to determine if the direction of the amplitude comparisons are, in fact, as expected. In reference to Hypothesis 3b, the direction of the amplitude differences between reading and drawing is according to expectation. That is, the low group did show more activation during drawing than reading on the right hemisphere but the finding is not statistically significant. Since the direction of amplitude differences between reading and drawing on the left hemisphere of high readers is inconsistent from trial 1 to trial 2, no interpretation can be made regarding Hypothesis 4a which

states that alpha amplitude measures for reading will be less than those for drawing. The hypothesis is clearly not confirmed by the results. However, the direction of the difference between reading and drawing on the right hemisphere is, in fact, in accordance with expectation (Hypothesis 4b). That is, high readers engaged the right hemisphere more during drawing than reading but this finding did not attain statistical significance. In sum, although conclusive evidence for the notion of hemispheric specialization is lacking for Grade 6 students, if it does exist then it is more likely to be found for spatial tasks than for linguistic tasks.

Summary Interpretation of Results from the General Model

A number of conclusions can be summarized regarding the differential involvement of the hemispheres and conditions for the low and high reading groups. First, subjects at both grade levels displayed more activation on the left hemisphere than on the right. Secondly, the Grade 6 low reading group displayed more activation than the high reading group. Thirdly, conclusive evidence for hemispheric specialization of subjects for both grade levels is lacking. Fourthly, regarding the direction of differences between reading and drawing, mild support for Hypothesis 2b, 3b, and 4b can be gleaned from the results. However, in the absence of statistical significance, such a conclusion is to be interpreted with great caution. Obviously, interpretations regarding the difference between low and high reading groups are not warranted on the basis of the results. Since similar nonsignificant results were obtained from the composite model (trial 1 plus trial 2), it will not be discussed.

The Task Minus Rest Model

Grade 3. Statistically significant differences were not found for either main effects or interactions for subjects at the Grade 3 level. Also, since the absolute value of the difference between reading or drawing and resting was calculated, comments regarding the direction of the difference between reading and drawing (i.e., more or less cognitive activation) cannot be made. However, one can speculate on which tasks

(reading or drawing) produced a greater or lesser shift from baseline resting. In reference to Table 16, it can be seen that on the left hemisphere the drawing condition produced a greater shift from baseline for both groups. This may suggest that the left hemisphere was more sensitive to the drawing task than to the reading task but such a conclusion is highly speculative. On the right hemisphere, there was virtually no difference between the reading and drawing condition during Trial 2. For Trial 1, the low group displayed a greater shift from baseline for reading than drawing, whereas, the high group displayed the opposite pattern. These results are largely uninterpretable.

Grade 6. In general, results from the Grade 6 task without the resting data suggest that a greater shift from baseline occurred for the right hemisphere compared to the left and for the high group compared to the low group. It is conceivable that the right hemisphere was more sensitive to or conducive to task requirements than the left hemisphere. Also, it is possible that the high reading group was more sensitive to neurophysiological changes in response to cognitive challenges than the low group. It should be noticed that the right hemisphere displayed a significantly greater shift from baseline during reading than during drawing for the high reading group on Trial 1 (Table 18). According to Table 10, both reading and drawing conditions obtained lower amplitude values (greater activation) than resting. Therefore, drawing was more highly activated than reading on the right hemisphere of the high reading group. This speculative finding is in accordance with Hypothesis 4b and is a sign of hemispheric specialization for nonverbal information processing. Further interpretations would be misleading.

Summary

If any statements on the relationship between reading ability and hemispheric specialization can be made on the basis of the results of this study, only two appear to have slight credibility. First, Grade 3 low readers may be specialized for processing verbal information.

According to Bakker, this would be dysfunctional -- a premature application of syntactic - semantic strategies (Type 1 dyslexia). Secondly, both Grade 6 low and high readers appear to be specialized to process nonverbal information. According to Satz and his associates, this is to be expected. Finally, these conclusions are speculative and should be interpreted with a great deal of caution. The remainder of this chapter is devoted to a disucssion of directions for further research.

DIRECTIONS FOR FURTHER RESEARCH

First theoretical and then practical directions for further research will be entertained. The major pursuit here is to suggest how research might be extended beyond its present state such that a clearer understanding of hemispheric specialization may be achieved. It is this interaction between theoretical constructs and applied research that acts as an impetus for gaining scientific knowledge.

Consider the hypothetical construct of hemispheric specialization. On the basis of existing research, it would appear that a credible model does exist, at least, for normal right-handed adults. What is not known is whether or not hemispheric specialization is a developmental phenomenon and whether or not it is related to reading problems. To be sure, better theoretical formulations are required in these two areas. For example, hemispheric specialization may be complete at birth, present at birth but continually developing, or it may be a secondary manifestation of cognitive development. What then are the alternatives for a model of reading difficulty based on the construct of cerebral asymmetry? Young children with reading problems may be overspecialized in processing verbal information. Or perhaps older children with reading problems are overspecialized in processing nonverbal information. A third possibility is that poor readers at an older age are under-specialized in processing verbal information. Fourthly, it may be that hemispheric specialization is not related to reading difficulty. Therefore, it is recommended here that more research on the relationship between cerebral asymmetry and reading difficulty is necessary to formulate a clear model.

A number of practical directions for further research in this area can be delineated. First, subjects selected for research must be of varying ages or longitudinal studies should be undertaken. Secondly, it would be beneficial to select subjects at varying levels of intellectual ability. Following these two suggestions would permit the researcher to observe hemispheric specialization across the age- and ability-range

of subjects. Thirdly, it is extremely important to subgroup poor readers on the basis of reading subskill deficiencies. Such a procedure is compatible with existing knowledge on reading disability. Fourthly, the electrophysiological techniques (frequency analysis and evoked potentials) are highly recommended to be used for assessment purposes. A related suggestion here is that electrophysiological recordings should be taken from many cerebral locations for the entire frequency bandwidth (1 - 32 cycles per second). In addition, this must be done during a number of verbal and nonverbal cognitive challenges of higher mentation. A fifth direction for further research is to use the regional cerebral blood flow technique (rCBF) to map the various areas of cerebral activation during various cognitive tasks. The rCBF technique is a more direct measure of cerebral function than EEG techniques. Lastly, at least two subject-related variables should be controlled for in these studies -- sex differences and handedness. Perhaps further research can, in fact, develop a clearer, more accurate model of the relationship between cerebral asymmetry and reading difficulty. Further research in this area seems to be warranted.

In conclusion, the focus of the present study was on neurophysiological assessment of reading disorders. On the basis of results from existing research studies and the study presented here, more theoretical and practical work is required in using neurophysiological techniques for diagnosing causes of reading problems. This must be done before neurophysiologically-based remediation of reading problems may be prescribed in reading clinics. Of course, the ultimate goal is remediation but a number of logically ordered and empirical steps must be taken prior to the attainment of that goal in this area of research.

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APPENDIX A

CORRESPONDENCE WITH PARENTS

LETTER TO PARENTS

Dear parent (guardian) of ________________________________:

Enclosed you will find a parental consent form and a statement on the purpose/procedures of the research study on reading. Please sign the form and send it in the envelope provided. In addition, please write down possible dates (June, July, August) that your child will be available. The study will be conducted at the University of Alberta (Education North, Room 6-136) on evenings (after 5:00 p.m.) and on Saturdays. The total time required for each child will be about 60 minutes.

You are invited to bring your child and see the Biocomp computer but if you cannot come to the University, transportation will be provided for your child. If you have any questions please feel free to call me at 455-7205 (home) or 429-5621, ext. 686 (work). Thank you for your interest in this exciting research project.

Sincerely,

Dave Mensink
Graduate Student
Educational Psychology
University of Alberta

P.S. If you would prefer to see the Biocomp before signing the consent form, this can be arranged.

PURPOSE AND PROCEDURES OF THE RESEARCH

PURPOSE: To determine if children with reading difficulty read in a different manner than children who do not have reading difficulty. And to determine how to teach children with reading difficulty in the best possible manner.

PROCEDURES:

1. The children will be invited to look at and "play" with the measuring instrument. The instrument is called the Biocomp and it is a computer which can measure brain waves, muscle tension, temperature, and other body functions.

2. Then an elastic headband will be placed on the child's head and little silver cups will be placed under the headband.

3. Next, the child will be asked to read a short passage, to copy a design, and to rest and think of nothing.

4. The children will be asked to read, draw and rest four times each. The procedures will last about 60 minutes for each child.

Children will not have to sit still during the study and they will probably enjoy their experience with the Biocomp.

PARENTAL CONSENT FORM

I, ______________________________ (parent's name), agree to let my child, ______________________________ (child's name), participate in a research project to be conducted at the University of Alberta by David L. Mensink (graduate student) under the supervision of C. T. King (Associate Professor). I will bring my child to the University of Alberta or allow him/her to be transported to and from the University in a vehicle adequately covered by insurance.

I understand the purpose and procedures of the research project and I am fully aware that the procedures will cause no pain or discomfort to my child. I understand that I may ask the researchers to discuss the results with me and that I may request to see a demonstration of the Biocomp.

Signature ______________________________

Date ______________________________

The University of Alberta
Faculty of Education
Department of Educational Therapy
Area of Special Education

APPENDIX B

CORRELATION TABLES

Table a

Pearson correlations between Ability/Achievement and EEG Amplitudes during Reading, Drawing and Resting

	Left Hemisphere			Right Hemisphere		
	Read	Draw	Rest	Read	Draw	Rest
Grade 3 - Trial 1 (n=14)						
Slosson I.Q.	-.511*	-.641**	-.400	-.351	-.495*	-.307
Decoding plus Comp.	-.181	-.535*	-.427	-.090	-.052	-.250
Grade 3 - Trial 2 (n=14)						
Slosson I.Q.	-.323	-.432	-.045	-.345	-.312	-.520**
Decoding plus Comp.	.066	-.096	.074	-.114	-.107	-.088
Grade 6 - Trial 1 (n=14)						
Slosson I.Q.	.196	.311	.356	-.055	.482*	.551*
Decoding plus Comp.	.135	.438	.481*	-.093	.513*	.562*
Grade 6 - Trial 2 (n=14)						
Slosson I.Q.	.238	.331	.229	.306	.253	.446
Decoding plus Comp.	.298	.374	.377	.286	.288	.431

* $p < .05$

** $p < .01$

Table b

Pearson Correlations of EEG Amplitude between Trial 1 and Trial 2 during Reading, Drawing, and Resting

Grade 3	Read (Trial 1:Trial 2)	Draw (Trial 1:Trial 2)	Rest (Trial 1:Trial 2)
Left Hemisphere	.925***	.779***	.206
Right Hemisphere	.877***	.796***	.556*
Grade 6			
Left Hemisphere	.897***	.816***	.887***
Right Hemisphere	.638**	.906***	.749***

Table c

Pearson Correlations of EEG Amplitude between Left and Right Hemispheres during Reading, Drawing, and Resting

Grade 3 (n=14)	Read (Left:Right)	Draw (Left:Right)	Rest (Left:Right)
Trial 1	.387	.377	.058
Trial 2	.586*	.631*	.373
Grade 6 (n=14)			
Trial 1	.307	.271	.691**
Trial 2	.097	.513*	.329

* $\underline{p} < .05$

** $\underline{p} < .01$

*** $\underline{p} < .001$

Table d

Pearson Correlations of EEG Amplitudes between

Reading, Drawing, and Resting Conditions

Grade 3 (n=14)

Left Hemisphere	Left Hemisphere Draw	Left Hemisphere Rest
Trial 1		
Read	.809***	.545*
Draw	-	.744***
Trial 2		
Read	.910***	.762***
Draw	-	.704***

Grade 3 (n=14)

Right Hemisphere	Right Hemisphere Draw	Right Hemisphere Rest
Trial 1		
Read	.863***	.534***
Draw	-	.354
Trial 2		
Read	.895***	.940***
Draw	-	.930***

Grade 6 (n=14)

Left Hemisphere	Left Hemisphere Draw	Left Hemisphere Rest
Trial 1		
Read	.700***	.799***
Draw	-	.882***
Trial 2		
Read	.948***	.946***
Draw	-	.911***

Grade 6 (n=14)

Right Hemisphere	Right Hemisphere Draw	Right Hemisphere Rest
Trial 1		
Read	.108	-.063
Draw	-	.659**
Trial 2		
Read	.509*	.704**
Draw		.888***

* $p < .05$
** $p < .01$
*** $p < .001$

APPENDIX C

TECHNICAL SPECIFICATIONS

BIOCOMP 2001

OUTLINE OF TECHNICAL SPEC'S FOR BIDDING PURPOSES

1 -	Apple II Computer	24K memory
1 -	Biocomp Program	Operates sensor, stores, displays information.
1 -	Biocomp Program	Capable of making measures on 4 channels, choice of 7 different modalities; EMG, EEG, PPV, TMP. SCR. SPR, and HRT (see details below)
2 -	Biocomp Telemetric Units	Communicate via infra-red light, Range: 20 feet, line of sight.
4 -	Sets of Elctrodes	1 Plethysmograph, 1 Temperature Probe, 1 Standard, 3 lead electrode, 1 three lead alligator electrode.

MODALITIES - Any combination of Four, simultaneously.

EMG = Electromyograph, 4 bands (80-400); (15-100); (80-1000)
TMP = Temperature Fahrenheit or centigrade
PPV = Peak Pulse Volume
SCR = Skin Conductance and Response (GSR)
EEG = Alpha, Beta, Theta, Alpha-Theta frequency bands
SPR = Skin Potential and Response
HRT = Heart Rate

EMG COMMON MODE REJECTION] 30db at 60 Hz

RESOLUTION OF DIGITAL READING 1 part in 4000

Noise level: Short circuit input 8 nv/VHz 10 to 1000 Hz
0.25 microvolts RMS, 15 to 1000 hz
Displays: Simultaneous Graphic and Digital

SCALE RANGES:

0 to 30 Mv 4 significant figures eg: 28.42 Mv 10 to 409.5

Autoranging occurs when input falls below
or when input exceeds:
10 Mv
30 Mv

ll EEG - 4 FREQUENCY BANDS

A - Alpha (7 - 13) Hz
B - Beta (12 - 30) Hz
T - Theta (4 - 8) Hz
W (4 - 30) Hz

COMMON MODE REJECTION

] 30 db @ 60 Hz
] 00 db at 15 Hz

NOISE LEVELS:

See EMG

SCALES - Auto Ranging:

See EMG

DISPLAYS:

Digital and Graphic

III SCR SKIN CONDUCTANCE $ RESPONSE

Ac Excitation 7 Hz
Not affected by electrode polarization
Resolution of Digital Readout: 1 part in 4000 of full scale

IV SPR SKIN POTENTIAL AND RESPONSE

Scales

0 - 100 millivolts DC
resolution 1 part in 4000 of full scale

V TMP

60.00 to 100.0 deg F; .01 degree F Resolution
15.56 to 37.77 deg C; .01 degree C REsolution

VI HRT = Heart Rate

Timed on alternate beats
30.0 to 130 Bpm
Resolution: lBpm
Transducer: plethysmograph

VII PPV = Peak Pulse Volume
0 to 100 millivolts
Resolution: one part in 4000 of full scale
Transducer: plythsmograph

PROGRAMMED FUNCTIONS:

1 Timer: Records culmutive
time over measurement sessions

2 Integrating and averaging functions
Records 38 averages for each channel
at selected times .1 to 99 seconds

4 Variance = squared
Standard deviation
Calculated and recorded for each of the above items

SOUND

Musical half tones change at resolution level
Major 3rd and Major 5th tones differentiate threshold levels

POWER

All Biocomp modules that are in electro-physical contact are battery operated 1 6 volt 1 amp Hr Storage battery in each Tranceiver module by computer power

Operating time: 10 Hrs/charge, one battery on charge
other is being used.

Computer power 115V ± 10% 50 - 60 Hz for Apple Computer.
<u>No physiological electric contact between subject and computer</u>.

TELEMETER:

Infrared frequency modulated 100 ±]0 Khz deviation
Max Range 20'
60° off axis Range: 10'

Two way digital data Transmission

MONITOR:

Standard color television receiver
not supplied

DIMENSIONS

Computer Apple II

Size; $15\frac{1}{2}$" w x 18" d x $4\frac{1}{4}$" h
Keyboard size; 10" w x 3 3/4"
Weight; 12 lbs.

Disk II;

Size; 6 1/8" w x 8 3/4" d x 3 3/4"
Weight lbs.

Telemetric Units: (2)

Size: 3 1/8" w x 5 7/8" d x 2" h
Weight; 1 lb.

Sensor:

Size; 3 1/8" w x 5 7/8" d x 2" h
Weight;]2 oz's

Overall shipping weight:

Approximately 30 lbs.

APPENDIX D

STIMULUS MATERIALS

GRADE 3 READING SAMPLE

How Percival Caught the Tiger

Percival Summers went to the jungle to trap wild animals for the circus. He had some brave jungle boys with him.

One day they were walking through the jungle looking for tracks of wild animals.

All at once Percival saw a tiger.

The tiger saw Percival.

Percival was so scared he jumped right out of his shoes.

The boys and Percival ran as fast as they could until they were out of danger. Then they sat down to think.

Percival thought and thought. He wanted to catch that tiger.

He called his brave boy Joe and said, "What in all this world do tigers like best to eat?"

Joe thought and thought.

At last he said, "The things that tigers like best in all this world are baked sweet potatoes covered with brown sugar and butter."

Percival was very much surprised.

He sent two boys to a faraway village for a big basket of sweet potatoes. The others made a cage with a big trap door in the top.

When the boys came with the sweet potatoes, Percival baked them all. When they were done, he cut them open and put a stone inside each one. Then he closed them again so they would look all right to the tiger. He covered the potatoes with brown sugar and butter.

Percival and his brave boys went to the jungle. They carried the cage, the sweet potatoes and a long rope.

They put the sweet potatoes where the tiger would be sure to find them.

They waited.

Pretty soon they heard the tiger roar. He sniffed the sweet potatoes and began to eat them.

He was in such a hurry he swallowed them whole and never knew there was a stone in each one.

His body began to hang down and down, until it was hanging right down on the ground, because he was so full of whole sweet potatoes and stones.

The tiger was so full that he couldn't move or turn around. Percival and his boys could go near him without danger. They tied his back legs together with the long rope and threw one end over a branch of a tree.

They pulled him into the air. The tiger didn't like that. He kicked and kicked uhtil the branch was about to break. Stones fell from his mouth. They fell and fell until the tiger was empty again.

The brave jungle boys got the big cage, let him down into it, and closed the door. They named him Sweet Potato and sent him to the circus.

That is how Percival caught the tiger.

GRADE 6 READING SAMPLE

Blast-off

"All hands! Acceleration stations - prepare to blast off." I went back to my couch and the stewardess made sure that we were all strapped down. She cautioned us not to unstrap until she said we could. She went down to the deck below.

I felt my ears pop and there was a soft sighing in the ship. I swallowed and kept swallowing. I knew what they were doing: blowing the natural air out and replacing it with the standard helium-oxygen mix at half sea-level pressure. But the woman - the same one - didn't like it. She said, "Joseph, my head aches. Joseph, I can't breathe. Do something!"

Then she clawed at her straps and sat up. Her husband sat up, too, and forced her back down.

The Bifrost tilted over a little and the speaker said, "Minus three minutes!"

After a long time it said, "Minus two minutes!"

And then "Minus one minute!" and another voice took up the count: "Fifty-nine! Fifty-eight! Fifty-seven!"

My heart started to pound so hard I could hardly hear it. But it went on: " - Thirty-five! Thirty-four! Thirty-three! Thirty-two! Thirty-one! Half! Twenty-nine! Twenty-eight!"

And it got to be: "Ten!"

And "Nine! Eight! Seven! And six! And five! And four! And three! And two -"

I never did hear them say "one" or "fire" or whatever they said. About then something fell on me and I thought I was licked. Once, exploring a cave with some fellows, a bank collapsed on me and I had to be dug out. It was like that - but nobody dug me out.

My chest hurt. My ribs seemed about to break. I couldn't lift a finger. I gulped and couldn't get my breath.

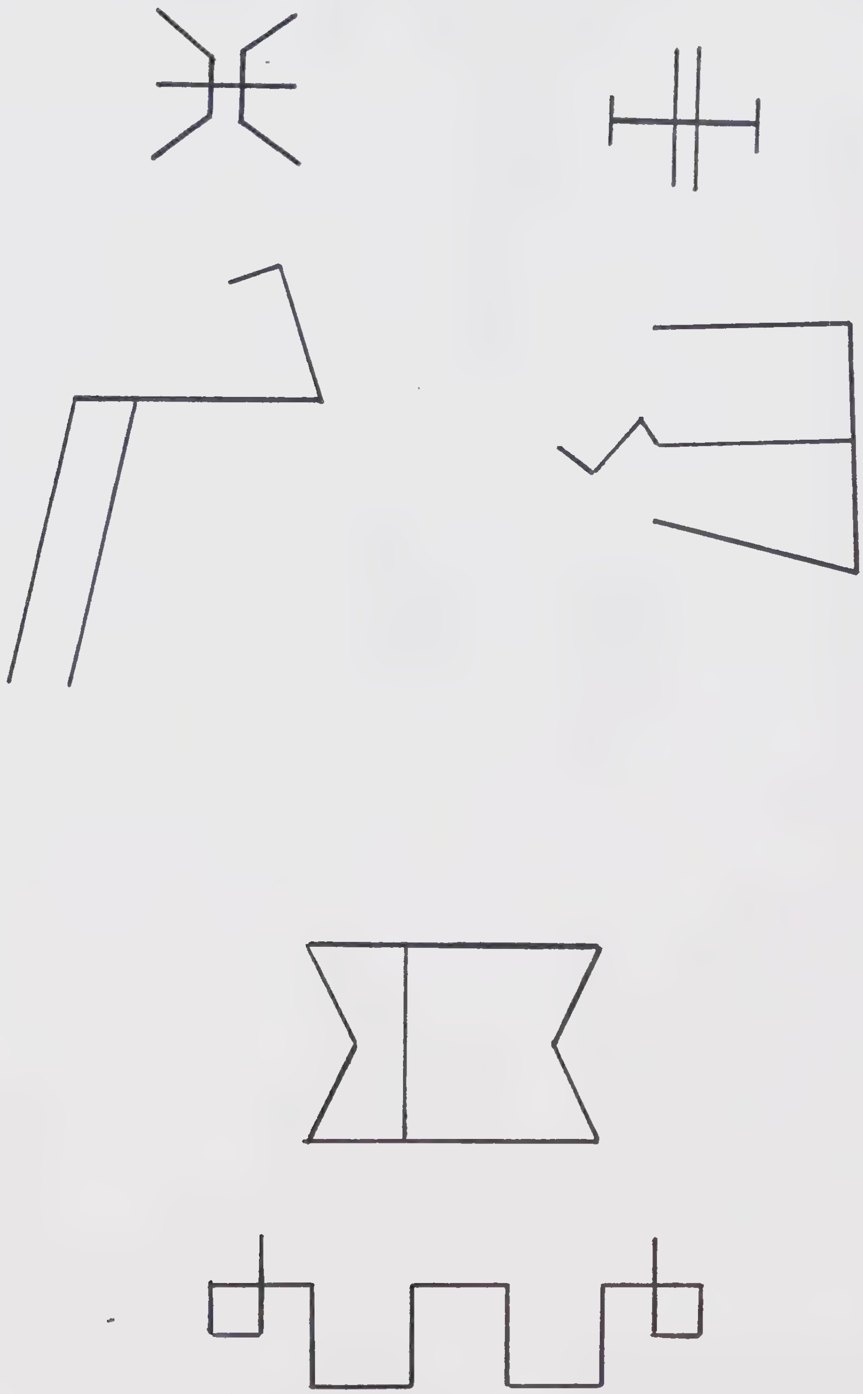
I wasn't scared, not really, because I knew we would take off with a high g, but I was awfully uncomfortable. I managed to turn my head a little and saw that the sky was already purple. While I watched, it turned black and the stars came out, millions of stars. And yet the Sun was still streaming in through the port.

The roar of the jets was unbelievable but the noise started to die out almost at once and soon you couldn't hear it at all. They say the old ships used to be noisy even after you passed the speed of sound; the Bifrost was not. It got as quiet as the inside of a bag of feathers.

There was nothing to do but lie there, stare out at the black sky, try to breathe and try not to think about the weight sitting on you.

And then, so suddenly that it made your stomach turn flip-flops, you didn't weight anything at all.

SAMPLES OF NONMEANINGFUL DESIGNS



APPENDIX E

SUMMARY ANOVA AND CONTRAST TABLES

Table e

Summary of 2x2x3 ANOVA (General):

Grade 3 - Trial 1

Source of Variation	SS	DF	MS	F	P
Between Subject	224.90	13			
A	0.0	1	0.0	9.9	1.00
Subj. w. Group	224.90	12	18.71		
Within Subjects	273.44	70			
B	32.07	1	32.07	3.9	0.09
AB	0.20	1	0.20	0.02	0.89
B X Subj. w. Group	113.63	12	9.47		
C	5.23	2	2.62	1.15	0.33
AC	5.31	2	2.65	1.17	0.33
C X Subj. w. Group	54.43	24	2.27		
BC	0.79	2	0.39	0.18	0.84
AC	8.56	2	4.28	1.93	0.17
BC X Subj. w. Group	53.23	24	2.22		

A = Group (low and high readers)
B = Hemisphere (left and right)
C = Task (read, draw, rest)

Table f

Summary of Contrasts (General):

Grade 3 - Trial 1

Contrasts	Mean Diff.	Mean Sq.	DF 1	DF 2	F	P
Low Left - High Left	-0.10	14.11	1.	24.	0.01	0.94
Low Right - High Right	0.10	14.11	1.	24.	0.01	0.95
Low Left - Low Right	-1.33	9.47	1.	12.	1.97	0.19
High Left - High Right	-1.14	9.47	1.	12.	1.44	0.25
Low Read - High Read	-0.14	7.76	1.	36.	0.03	0.87
Low Draw - High Draw	-0.54	7.76	1.	36.	0.39	0.54
Low Rest - High Rest	0.67	7.76	1.	36.	0.61	0.44
Low Read - Low Draw	0.01	2.27	1.	24.	0.00	0.98
Low Read - Low Rest	0.01	2.27	1.	24.	0.00	0.99
Low Draw - Low Rest	-0.01	2.27	1.	24.	0.00	0.99
High Read - High Draw	-0.38	2.27	1.	24.	0.66	0.42
High Read - High Rest	0.82	2.27	1.	24.	3.12	0.09
High Draw - High Rest	1.20	2.27	1.	24.	6.67	0.02
Left Read - Right Read	-4.6	4.63	1.	36.	4.81	0.04
Left Draw - Right Draw	-1.26	4.63	1.	36.	3.62	0.07
Left Rest - Right Rest	-0.99	4.63	1.	36.	2.20	0.15
Left Read - Left Draw	-0.28	2.24	1.	48.	0.24	0.63
Left Read - Left Rest	0.18	2.24	1.	48.	0.10	0.75
Left Draw - Left Rest	0.46	2.24	1.	48.	0.65	0.42
Left Read - Right Draw	-0.09	2.24	1.	48.	0.02	0.88
Right Read - Right Rest	0.65	2.24	1.	48.	1.32	0.26
Right Draw - Right Rest	0.74	2.24	1.	48.	1.69	0.20

Table g

Summary of 2x2x3 ANOVA (General):

Grade 3 - Trial 2

Source of Variation	SS	DF	MS	F	P
Between Subjects	196.43	13			
A	1.98	1	1.98	0.12	0.73
Subj. W. Group	194.44	12	16.20		
Within Subjects	124.99	70			
B	20.50	1	20.50	4.69	0.05
AB	0.82	1	0.82	0.19	0.67
BX Subj. W. Group	52.44	12	4.37		
C	15.75	2	7.88	8.28	0.002
AC	0.93	2	0.47	0.05	0.95
CX Subj. W. Group	22.83	24	0.95		
BC	0.43	2	0.22	0.48	0.62
AC	1.38	2	0.69	1.54	0.24
BCX Subj. W. Group	10.74	24	0.45		

A = Grade (Low and High Readers)
B = Hemisphere (left and right)
c = Task (read, draw, rest)

Table h

Summary of Contrasts (General):

Grade 3 - Trial 2

Contrasts	Mean Diff.	Mean Sq.	DF1	DF2	F	P
Low Left - High Left	-0.50	10.29	1.	24.	0.17	0.68
Low Right - High Right	-0.11	10.29	1.	24.	0.01	0.39
Low Left - Low Right	-1.19	4.37	1.	12.	3.38	0.09
High Left - High Right	-0.79	4.37	1.	12.	1.50	0.24
Low Read - High Read	-0.40	6.04	1.	36.	0.28	0.60
Low Draw - High Draw	-0.24	6.04	1.	36.	0.10	0.75
Low Rest - High Rest	0.28	6.04	1.	36.	0.14	0.72
Low Read - Low Draw	-0.12	0.95	1.	24.	0.16	0.69
Low Read - Low Rest	0.84	0.95	1.	24.	7.71	0.01
Low Draw - Low Rest	0.96	0.95	1.	24.	10.11	0.004
High Read - High Draw	0.04	0.95	1.	24.	0.01	0.91
High Read - High Rest	0.96	0.95	1.	24.	10.11	0.004
High Draw - High Rest	0.92	0.95	1.	24.	9.37	0.01
Left Read - Right Read	-1.17	1.76	1.	36.	8.21	0.01
Left Draw - Right Draw	-0.97	1.76	1.	36.	5.65	0.02
Left Rest - Right Rest	-0.82	1.76	1.	36.	4.04	0.05
Left Read - Left Draw	-0.14	0.70	1.	48.	0.20	0.65
Left Read - Left Rest	0.72	0.70	1.	48.	5.21	0.03
Left Draw - Left Rest	0.86	0.70	1.	48.	7.48	0.01
Right Read - Right Draw	0.01	0.70	1.	48.	0.03	0.86
Right Read - Right Rest	1.07	0.70	1.	48.	11.49	0.001
Right Draw - Right Rest	1.01	0.70	1.	48.	10.30	0.002

Table i

Summary of 2x2x3 ANOVA (General):

Grade 6 - Trial 1

Source of Variation	SS	DF	MS	F	P
Between Subjects	242.52	13			
A	112.24	1	112.24	10.34	0.01
Subj. W. Group	130.28	12	10.86		
Within Subjects	374.72	70			
B	24.65	1	24.65	3.63	0.08
AB	0.53	1	0.53	0.08	0.78
BX Subj. W. Group	81.38	12	6.78		
C	12.07	2	6.04	1.04	0.37
AC	8.09	2	4.04	0.70	0.51
CX Subj. W. Group	138.93	24	5.79		
BC	6.56	2	3.28	0.81	0.46
AC	5.30	2	2.65	0.65	0.53
BCX Subj. W. Group	97.21	24	4.05		

A = Group (low and high readers)
B = Hemisphere (left and right)
C = Task (read, draw, rest)

Table j

Summary of Contrasts (General):

Grade 6 - Trial 1

Contrasts	Mean Diff.	Mean Sq.	DF1	DF2	F	P
Low Left - High Left	-2.15	8.82	1.	24.	3.68	0.07
Low Right - High Right	-2.47	8.82	1.	24.	4.85	0.04
Low Left - Low Right	-0.92	6.78	1.	12.	1.32	0.27
High Left - High Right	-1.24	6.78	1.	12.	2.39	0.15
Low Read - High Read	-1.59	7.48	1.	36.	3.56	0.07
Low Draw - High Draw	-2.24	7.48	1.	36.	7.02	0.01
Low Rest - High Rest	-3.11	7.48	1.	36.	13.56	0.001
Low Read - Low Draw	0.79	5.79	1.	24.	1.14	0.30
Low Read - Low Rest	1.69	5.79	1.	24.	5.15	0.03
Low Draw - Low Rest	0.89	5.79	1.	24.	1.45	0.24
High Read - High Draw	0.15	5.79	1.	24.	0.04	0.84
High Read - High Rest	0.17	5.79	1.	24.	0.05	0.82
High Draw - High Rest	0.02	5.79	1.	24.	0.00	0.98
Left Read - Right Read	-1.49	4.96	1.	36.	4.72	0.04
Left Draw - Right Draw	-0.29	4.96	1.	36.	0.18	0.67
Left Rest - Right Rest	-1.46	4.96	1.	36.	4.54	0.04
Left Read - Left Draw	-0.13	4.92	1.	48.	0.02	0.88
Left Read - Left Rest	0.91	4.92	1.	48.	1.19	0.28
Left Draw - Left Rest	1.04	4.92	1.	48.	1.55	0.22
Right Read - Right Draw	1.07	4.92	1.	48.	1.63	0.21
Right Read - Right Rest	0.94	4.92	1.	48.	1.27	0.27
Right Draw - Right Rest	-0.13	4.92	1.	48.	0.02	0.88

Table k

Summary of 2x2x3 ANOVA (General):

Grade 6 - Trial 2

Source of Variation	SS	DF	MS	F	P
Between Subjects	379.69	13			
A	147.47	1	147.47	7.62	0.02
Subj. W. Group	232.22	12	19.35		
Within Subjects	333.48	70			
B	27.55	1	27.55	1.79	0.21
AB	1.57	1	1.57	0.10	0.75
BX Subj. W. Group	184.21	12	15.35		
C	4.83	2	2.42	1.31	0.29
AC	0.95	2	0.48	0.26	0.78
CX Subj. W. Group	44.30	24	1.85		
BC	5.11	2	2.55	1.10	0.35
AC	9.20	2	4.60	1.98	0.16
BCX Subj. W. Group	55.76	24	2.32		

A = Group (low and high readers)
B = Hemisphere (left and right)
C = Task (read, draw, rest)

Table 1

Summary of Contrasts (General):

Grade 6 - Trial 2

Contrasts	Mean Diff.	Mean Sq.	DF1	DF2	F	P
Low Left - High Left	-2.38	17.35	1.	24.	2.28	0.14
Low Right - High Right	-2.92	17.35	1.	24.	3.45	0.08
Low Left - Low Right	-0.87	15.35	1.	12.	0.52	0.49
High Left - High Right	-1.42	15.35	1.	12.	1.38	0.26
Low Read - High Read	-2.66	7.68	1.	36.	9.65	0.004
Low Draw - High Draw	-2.39	7.68	1.	36.	7.78	0.01
Low Rest - High Rest	-2.91	7.68	1.	36.	11.55	0.002
Low Read - Low Draw	0.41	1.85	1.	24.	0.98	0.33
Low Read - Low Rest	0.58	1.85	1.	24.	1.90	0.18
Low Draw - Low Rest	0.16	1.85	1.	24.	0.15	0.70
High Read - High Draw	0.69	1.85	1.	24.	2.68	0.12
High Read - High Rest	0.33	1.85	1.	24.	0.61	0.44
High Draw - High Rest	-0.36	1.85	1.	24.	0.73	0.40
Left Read - Right Read	-1.11	6.67	1.	36.	1.96	0.17
Left Draw - Right Draw	-0.56	6.67	1.	36.	0.49	0.49
Left Rest - Right Rest	-1.76	6.67	1.	36.	4.90	0.03
Left Read - Left Draw	0.27	2.08	1.	48.	0.25	0.62
Left Read - Left Rest	0.78	2.08	1.	48.	2.04	0.16
Left Draw - Left Rest	0.51	2.08	1.	48.	0.86	0.36
Right Read - Right Draw	0.83	2.08	1.	48.	2.31	0.14
Right Read - Right Rest	0.13	2.08	1.	48.	0.06	0.82
Right Draw - Right Rest	-0.70	2.08	1.	48.	1.65	0.21

Table m

Summary of 2x2x3 ANOVA (Trial 1 plus Trial 2):

Grade 3

Source of Variation	SS	DF	MS	F	P
Between Subjects	201.61	13			
A	0.57	1	0.57	0.03	0.86
Subj W. Group	201.04	12	16.75		
Within Subjects	154.23	70			
B	26.41	1	26.41	4.30	0.06
AB	0.47	1	0.47	0.08	0.79
BX Subj. W. Group	73.75	12	6.15		
C	9.50	2	4.75	4.49	0.02
AC	1.38	2	0.69	0.65	0.53
CX Subj. W. Group	25.38	24	1.06		
BC	0.54	2	0.27	0.42	0.66
AC	1.37	2	0.69	1.06	0.36
BCX Subj. W. Group	15.43	24	0.64		

A = Group (low and high readers)
B = Hemisphere (left and right)
C = Task (read, draw, rest)

Table n

Summary of Contrasts (Trial 1 plus Trial 2):

Grade 3

Contrasts	Mean Diff.	Mean Sq.	DF1	DF2	F	P
Low Left - High Left	-0.31	11.45	1.	24.	0.60	0.81
Low Right - High Right	-0.01	11.45	1.	24.	0.00	0.99
Low Left - Low Right	-1.27	6.15	1.	12.	2.76	0.12
High Left - High Right	-0.97	6.15	1.	12.	1.61	0.23
Low Read - High Read	-0.29	6.29	1.	36.	0.14	0.71
Low Draw - High Draw	-0.40	6.29	1.	36.	0.27	0.61
Low Rest - High Rest	0.19	6.29	1.	36.	0.06	0.81
Low Read - Low Draw	-0.05	1.06	1.	24.	0.03	0.88
Low Read - Low Rest	0.41	1.06	1.	24.	1.70	0.20
Low Draw - Low Rest	0.46	1.06	1.	24.	2.14	0.16
High Read - High Draw	-0.16	1.06	1.	24.	0.27	0.61
High Read - High Rest	0.89	1.06	1.	24.	7.92	0.01
High Draw - High Rest	1.06	1.06	1.	24.	11.10	0.003
Left Read - Right Read	-1.31	2.48	1.	36.	7.32	0.01
Left Draw - Right Draw	-1.13	2.48	1.	36.	5.40	0.03
Left Rest - Right Rest	-0.92	2.48	1.	36.	3.60	0.07
Left Read - Left Draw	-0.20	0.85	1.	48.	0.33	0.57
Left Read - Left Rest	0.46	0.85	1.	48.	1.72	0.20
Left Draw - Left Rest	0.66	0.85	1.	48.	3.56	0.07
Right Read - Right Draw	-0.01	0.85	1.	48.	0.00	0.97
Right Read - Right Rest	0.85	0.85	1.	48.	5.95	0.02
Right Draw - Right Rest	0.86	0.85	1.	48.	6.15	0.02

Table o

Summary of 2x2x3 ANOVA (Trial 1 plus Trial 2):

Grade 6

Source of Variation	SS	DF	MS	F	P
Between Subjects	293.65	13			
A	129.26	1	129.26	9.44	0.01
Subj. W. Group	164.39	12	13.70		
Within Subjects	294.70	70			
B	26.30	1	26.30	2.67	0.13
AB	1.05	1	1.05	0.11	0.75
BX Subj. W. Group	118.17	12	9.85		
C	7.32	2	3.66	1.28	0.30
AC	2.95	2	1.47	0.51	0.61
CX Subj. W. Group	68.87	24	2.87		
BC	5.32	2	2.66	1.09	0.35
AC	6.11	2	3.05	1.25	0.30
BCX Subj. W. Group	58.61	24	2.44		

A = Group (low and high readers)
B = Hemisphere (left and right)
C = Task (read, draw, rest)

Table p

Summary of Contrasts (Trial 1 plus Trial 2):

Grade 6

Contrasts	Mean Diff.	Mean Sq.	DF1	DF2	F	P
Low Left - High Left	-2.26	11.77	1.	24.	3.03	0.10
Low Right - High Right	-2.70	11.77	1.	24.	4.35	0.048
Low Left - Low Right	-0.90	9.85	1.	12.	0.86	0.37
High Left - High Right	-1.34	9.85	1.	12.	1.92	0.19
Low Read - High Read	-2.13	6.48	1.	36.	7.34	0.01
Low Draw - High Draw	-2.31	6.48	1.	36.	8.68	0.01
Low Rest - High Rest	-3.00	6.48	1.	36.	14.59	0.001
Low Read - Low Draw	0.60	2.87	1.	24.	1.32	0.26
Low Read - Low Rest	1.14	2.87	1.	24.	4.72	0.04
Low Draw - Low Rest	0.54	2.87	1.	24.	1.05	0.32
High Read - High Draw	0.41	2.87	1.	24.	0.63	0.44
High Read - High Rest	0.26	2.87	1.	24.	0.26	0.62
High Draw - High Rest	-0.15	2.87	1.	24.	0.08	0.78
Left Read - Right Read	-1.31	4.91	1.	36.	3.69	0.06
Left Draw - Right Draw	-0.43	4.91	1.	36.	0.39	0.54
Left Rest - Right Rest	-1.61	4.91	1.	36.	5.57	0.02
Left Read - Left Draw	0.06	2.66	1.	48.	0.01	0.92
Left Read - Left Rest	0.85	2.66	1.	48.	1.90	0.17
Left Draw - Left Rest	0.79	2.66	1.	48.	1.63	0.21
Right Read - Right Draw	0.95	2.66	1.	48.	2.38	0.13
Right Read - Right Rest	0.55	2.66	1.	48.	0.80	0.38
Right Draw - Right Rest	-0.40	2.66	1.	48.	0.42	0.52

Table q

Summary of 2x2x2 ANOVA (Task minus Rest):

Grade 3 - Trial 1

Source of Variation	SS	DF	MS	F	'S
Between Subjects	70.25	13			
A	0.64	1	0.64	0.01	0.92
Subj. W. Group	70.19	12	5.85		
Within Subjects	139.06	42			
B	15.75	1	15.75	1.97	0.19
AB	0.64	1	0.64	0.01	0.93
BX Subj. W. Group	95.74	12	7.98		
C	0.39	1	0.39	0.43	C.53
AC	2.88	1	2.88	3.13	0.10
CX Subj. W. Group	11.04	12	0.92		
BC	1.06	1	1.06	1.15	0.31
ABC	1.06	1	1.06	1.15	0.31
BCX Subj. W. Group	11.07	12	0.92		

A = Group (low and high readers)
B = Hemisphere (left and right)
C - Task minus Rest (read-rest and draw-rest)

Table r

Summary of Contrasts (Task minus Rest)

Grade 3 - Trial 1

Contrasts	Mean Diff.	Mean Sq.	DF1	DF2	F	P
Low Left - High Left	-0.14	6.91	1.	24.	0.02	0.89
Low Right - High Right	0.00	6.91	1.	24.	0.00	1.00
Low Left - Low Right	-1.13	7.98	1.	12.	1.12	0.31
High Left - High Right	-0.99	7.98	1.	12.	0.87	0.37
Low Read - High Read	0.39	3.38	1.	24.	0.31	0.58
Low Draw - High Draw	-0.52	3.38	1.	24.	0.56	0.46
Low Read - Low Draw	0.29	0.92	1.	12.	0.62	0.45
High Read - High Draw	-0.62	0.92	1.	12.	2.94	0.11
Left Read - Right Read	-0.79	4.45	1.	24.	0.97	0.33
Left Draw - Right Draw	-1.34	4.45	1.	24.	2.81	0.11
Left Read - Left Draw	0.11	0.92	1.	24.	0.09	0.77
Right Read - Right Draw	-0.44	0.92	1.	24.	1.49	0.23

Table s

Summary of 2x2x2 ANOVA (Task minus Rest):

Grade 3 - Trial 2

Source of Variation	SS	DF	MS	F	P
Between Subjects	36.65	13			
A	0.71	1	0.71	0.02	0.88
Subj. W. Group	36.58	12	3.05		
Within Subjects	30.79	42			
B	0.98	1	0.98	0.94	0.35
AB	2.24	1	2.24	2.16	0.17
BX Subj. W. Group	12.44	12	1.04		
C	0.14	1	0.14	0.18	0.68
AC	0.58	1	0.58	0.07	0.79
CX Subj. W. Group	9.32	12	0.78		
BC	0.14	1	0.14	0.31	0.59
ABC	0.35	1	0.35	0.08	0.79
BCX Subj. W. Group	5.43	12	0.45		

A = Group (low and high readers)
B = Hemisphere (left and right)
C - Task minus Rest (read-rest and draw-rest)

Table t

Summary of Contrasts (Task minus Rest):

Grade 3 - Trial 2

Contrasts	Mean Diff.	Mean Sq.	DF1	DF2	F	P
Low Left - High Left	-0.47	2.04	1.	24.	0.76	0.39
Low Right - High Right	0.33	2.04	1.	24.	0.37	0.55
Low Left - Low Right	-0.66	1.04	1.	12.	2.98	0.11
High Left - High Right	0.14	1.04	1.	12.	0.12	0.73
Low Read - High Read	-0.14	1.91	1.	24.	0.07	0.80
Low Draw - High Draw	-0.01	1.91	1.	24.	0.00	0.99
Low Read - Low Draw	-0.16	0.78	1.	12.	0.24	0.63
High Read - High Draw	-0.04	0.78	1.	12.	0.01	0.92
Left Read - Right Read	-0.36	0.74	1.	24.	1.25	0.28
Left Draw - Right Draw	-0.16	0.74	1.	24.	0.25	0.62
Left Read - Left Draw	-0.20	0.61	1.	24.	0.46	0.51
Right Read - Right Draw	0.0	0.61	1.	24.	0.0	1.00

Table u

Summary of 2x2x2 ANOVA (Task minus Rest):

Grade 6 - Trial 1

Source of Variation	SS	DF	MS	F	P
Between Subjects	77.06	13			
A	3.50	1	3.50	0.57	0.46
Subj.W. Group	73.56	12	6.13		
Within Subjects	222.81	42			
B	23.92	1	23.92	5.03	0.045
AB	2.08	1	2.08	0.44	0.52
BX Subj. W. Group	57.09	12	4.76		
C	13.80	1	13.80	2.13	0.17
AC	0.41	1	0.41	0.06	0.81
CX Subj. W. Group	77.91	12	6.49		
BC	12.26	1	12.26	4.17	0.06
ABC	0.46	1	0.46	0.02	0.90
BCX Subj. W. Group	35.30	12	2.94		

A = Group (low and high readers)
B = Hemisphere (left and right)
C = Task minus Rest (read-rest and draw-rest)

Table v

Summary of Contrasts (Task minus Rest):

Grade 6 - Trial 1

Contrasts	Mean Diff.	Mean Sq.	DF1	DF2	F	P
Low Left - High Left	-0.11	5.44	1.	24.	0.02	0.90
Low Right - High Right	-0.89	5.44	1.	24.	1.01	0.33
Low Left - Low Right	-0.92	4.76	1.	12.	1.25	0.29
High Left - High Right	-1.69	4.76	1.	12.	4.22	0.06
Low Read - High Read	-0.67	6.31	1.	24.	0.50	0.49
Low Draw - High Draw	-0.33	6.31	1.	24.	0.12	0.73
Low Read - Low Draw	0.82	6.49	1.	12.	0.73	0.41
High Read - High Draw	1.16	6.49	1.	12.	1.46	0.25
Left Read - Right Read	-2.24	3.85	1.	24.	9.15	0.01
Left Draw - Right Draw	-0.37	3.85	1.	24.	0.25	0.62
Left Read - Left Draw	0.06	4.72	1.	24.	0.01	0.95
Right Read - Right Draw	1.93	4.72	1.	24.	5.52	0.03

Table w

Summary of 2x2x2 ANOVA (Task minus Rest):

Grade 6 - Trial 2

Source of Variation	SS	DF	MS	F	P
Between Subjects	51.13	13			
A	24.18	1	24.18	10.77	0.01
Subj. W. Group	26.94	12	2.25		
Within Subjects	75.39	42			
B	7.43	1	7.43	3.54	0.08
AB	3.50	1	3.50	1.67	0.22
BX Subj. W. Group	25.19	12	2.10		
BC	0.78	1	0.78	0.95	0.35
ABC	0.67	1	0.67	0.01	0.93
BCX Subj. W. Group	9.88	12	0.82		

A = Group (low and high readers)
B = Hemisphere (left and right)
C = Task minus Rest (read-rest and draw-rest)

Table x

Summary of Contrasts (Task minus Rest):

Grade 6 - Trial 2

Contrasts	Mean Diff.	Mean Sq.	DF1	DF2	F	P
Low Left - High Left	-0.81	2.17	1.	24.	2.14	0.16
Low Right - High Right	-1.81	2.17	1.	24.	10.61	0.003
Low Left - Low Right	0.23	2.10	1.	12.	0.17	0.68
High Left - High Right	-1.23	2.10	1.	12.	5.03	0.045
Low Read - High Read	-1.48	2.17	1.	24.	7.04	0.01
Low Draw - High Draw	-1.15	2.17	1.	24.	4.26	0.05
Low Read - Low Draw	0.30	2.10	1.	12.	0.30	0.59
High Read - High Draw	0.63	2.10	1.	12.	1.32	0.27
Left Read - Right Read	-0.96	1.46	1.	24.	4.46	0.045
Left Draw - Right Draw	-0.49	1.46	1.	24.	1.16	0.29
Left Read - Left Draw	0.23	1.46	1.	24.	0.25	0.62
Right Read - Right Draw	0.70	1.46	1.	24.	2.35	0.14

APPENDIX F

MISCELLANEOUS

Name: ______________________________ Age: _________ Sex: M F

LATERALITY SCALE

Hand Preference:

1.	Write with pencil	L	R	
2.	Throw a ball	L	R	
3.	Wind a watch	L	R	
4.	Hammer a nail	L	R	
5.	Brush teeth	L	R	
6.	Comb hair	L	R	
7.	Open door	L	R	
8.	Cut with scissors	L	R	
9.	Spread butter on bread	L	R	
10.	Open a box	L	R	Left ____ Right ____

Foot Preference:

11.	Kick ball	L	R	
12.	Step from chair	L	R	
13.	Hop on one foot	L	R	Left ____ Right ____

Ear Preference:

14.	Listen to watch	L	R	
15.	Put earphone in ear	L	R	
16.	Put telephone to ear	L	R	Left ____ Right ____

Eye preference:

17.	Look through telescope	L	R	
18.	Look with one eye	L	R	Left ____ Right ____

Total Left ____ Total Right ____

SEQUENCE OF CONDITIONS

Sequence	Order of Hemisphere	Order of Conditions
1	Left, Right	Read, Draw, Rest
2	Right, Left	Draw, Rest, Read
3	Left, Right	Rest, Read, Draw
4	Right, Left	Rest, Draw, Read
5	Left, Right	Draw, Read, Rest
6	Right, Left	Read, Rest, Draw

I.D. # ____________

Biocomp 2001

Name: ______________________________

Data Summary

Grade, 3 6

Sex M F

Laterality L R B

	Trial 1	Trial 2
EEG Left Hemisphere		
Read	________	________
Draw	________	________
Rest	________	________
EEG Right Hemisphere		
Read	________	________
Draw	________	________
Rest	________	________

SIT IQ ________

EPS Read Decode ________

EPS Read Comp ________

EPS Math ________